MANUAL ON UNDERGROUND CORROSION CONTROL IN RURAL ELECTRIC SYSTEMS

REA BULLETIN 161-23

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FOREWORD

Underground corrosion as related to electrical grounding has recently become an important subject to many in the electric utility industry. At the same time, knowledge about underground corrosion has been in a process of rapid change and development.

This manual has been prepared in response to an expressed need for instruction and guidance concerning underground corrosion and corrosion control for electric utility people. The emphasis is on rural electric distribution systems, which are the sources for most of the experience used in developing this material. However, because distribution grounds are solidly connected to substation and bulk power source grounds as well as to the grounds at loads served from the common-neutral electric system, all need to be considered together when deciding on steps for avoiding or controlling underground corrosion.

This bulletin supersedes REA Bulletin 161-23, Relieving Underground Corrosion on Multigrounded Rural Electric Lines, dated May 1963, and replaces REA Bulletin 61-11, Corrosion Control in Underground Rural Electric Distribution Systems.

Assistant Administrator - Electric

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MANUAL ON UNDERGROUND CORROSION CONTROL IN RURAL ELECTRIC SYSTEMS

PART I. OVERVIEW

With the great increase in construction of underground electric systems in recent years, there has been an increase in the number and severity of underground corrosion problems. Copper neutral wires of underground cable have been found to corrode. Also, there have been indications of accelerated corrosion of anchor rods and other buried metal structures connected to the electric neutral in the vicinity of underground cables.

Electric utility people are finding that new knowledge and new skills are needed in order to do corrosion testing, interpret results and take corrective actions. Utility people are also finding that the decisions about materials and designs for new construction require information that may not be readily available. This bulletin has been prepared to serve as a manual - a guide and reference for the electric utility manager, engineer or other employee who is confronted with underground corrosion problems.

Because of the extent and complexity of the subject, this manual is divided into five parts. Part I, Overview, gives a general picture of the present situation and ways of dealing with corrosion. Part II, Introduction to Corrosion, is for the individual who is new to this subject and faces situations that require detailed knowledge about corrosion. Parts III, Testing and Surveys, and IV, Corrective and Preventive Measures, provide technical guidance regarding corrosion testing and corrosion control. Part V, Stray Current Corrosion, deals specifically with corrosion due to pipeline protection rectifiers and other dc sources.

SEEING THE LARGER PICTURE

One major obstacle in dealing with underground corrosion is the tendency to consider a section of cable, an anchor rod or a buried pipe or tank without recognizing the larger picture. All of these buried metallic structures, when interconnected with electrical grounds, form a huge galvanic cell. Underground corrosion is largely due to galvanic effects resulting from dissimilarities, dissimilarities in metals and/or dissimilarities in the soil around them. Much of the discussion in Parts II and III of this bulletin is about these dissimilarities and about electrical tests which reveal what is happening.

Underground corrosion can be arrested or, in new construction, prevented by installing sacrificial anodes of magnesium or zinc for cathodic (corrosion) protection. Information to help in designing and installing such protection is included in Part IV.

As steps are taken to control corrosion, an immediate question follows: "How should we design and build new facilities to avoid corrosion problems at a reasonable cost"? This may be a difficult question. Effective and economical measures for corrosion control may require changes in long-established practices. Chief among these changes, and probably the most controversial, is the application of galvanized steel for ground rods and other parts of grounding systems that traditionally have been entirely of copper.

For underground cable, a number of preventive measures are suggested which may be new to many at the time of this writing. They are:

1. Avoid installation of bare-neutral cable in conduit, particularly in non-metallic conduit, where other choices are available.

2. Consider the installation of sacrificial anodes for corrosion control at the time new cables are installed.

3. Consider the installation of cables with a jacket over the concentric neutral wires, with additional grounding where necessary, if effective corrosion control cannot otherwise be assured at a reasonable cost.

Materials and designs for future construction are discussed in Part IV.

Pipeline protection rectifiers and other sources of direct current can cause rapid underground corrosion of electrical grounds and other buried metal connected to the electric neutral. The likelihood of stray-current corrosion is increasing because of pipeline safety regulations that call for installation of more cathodic protection rectifiers and other changes such as shared rights-of-way for electric and pipeline facilities. Control of stray-current corrosion is discussed in Part V.

THE NEED TO LEARN

Control of underground corrosion needs to be a major consideration in the design, construction and maintenance of an electric system, particularly one that includes underground facilities. At present, knowledge about power system underground corrosion and corrosion control is, unfortunately, quite limited among electric utility people.

The immediate task for many of us is to become educated about corrosion as quickly and as well as possible. This includes learning about corrosion and corrosion control, learning about soils in each service area, and learning how to apply corrective measures. This can best be accomplished by designating one or more specific employees in your organization to become educated about underground corrosion and corrosion control. With this specialized knowledge available, needed precautions can be taken and others in your organization can be adequately informed. This is particularly important if underground facilities are in operation or are being considered.

PART II. INTRODUCTION TO CORROSION

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PART II. INTRODUCTION TO CORROSION

This introduction is for the person who may have little experience in corrosion testing or in use of corrosion control measures. It can serve as a text and later as a reference. After studying this introduction and performing the experiments that are suggested, the novice should be able to understand most published articles and instructions about corrosion and corrosion testing. Those who use this manual will have an understanding of corrosion testing procedures and will be able to learn further from experience.

CORROSION: AN ELECTRICAL AND CHEMICAL PROCESS

Corrosion is both an electrical and chemical process. The electrical character of corrosion is such that:

- Underground corrosion can be caused, controlled or stopped by small dc voltages and currents, and

- Electrical test instruments can be and are used in underground corrosion testing.

The chemical character of corrosion is such that metallic ions, minute (electrically) charged particles, disassociate or remove themselves from a metal surface and chemically combine with other types of ions in the surrounding soil.

Let us picture a piece of iron buried in soil as shown in Fig. 1. In corroding, the iron releases ions represented as Fe, the chemical symbol for iron. Each iron ion is an atom of iron that has lost electrons (negative electrical charges). As a result of losing the electrons, the ion is positive as represented by the plus signs. Each time an ion escapes, the negative charge (abandoned electrons) remains on the metal and is represented in Fig. 1 by "minus" signs. Opposite charges attract each other, so it becomes more difficult for ions to escape as the metal becomes more negative. If conditions at the metal surface are uniform, a voltage (accumulation of electrons) is reached at which ions can no longer escape. In this condition, corrosion ceases. When steel or iron (or any other common metal) with a uniform surface is buried in relatively uniform soil, little corrosion occurs.

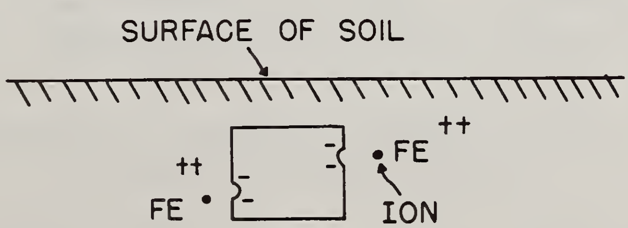

Fig. 1. Formation of ions in moist soil

The Importance of Dissimilarities

Let us take note that corrosion is largely caused by dissimilarities in metal surfaces and in the environment to which they are exposed. To say that buried metals corrode simply because the soil is corrosive and metals are corrodible is to overlook the most important causes and the best opportunities for minimizing corrosion.

An important dissimilarity occurs when unlike metals are connected together. Returning again to the iron buried in soil, bury a piece of copper near the iron as shown in Fig. 2. Like the iron, the copper loses ions and reaches a dc potential at which corrosion becomes insignificant. The copper is a less active metal than iron and therefore reaches a less negative potential. This is indicated by a plus (meaning less negative) sign next to the connecting lead to the copper.

If the iron and copper are connected together as shown in Fig. 3, a current flows to equalize the potential unbalance. Now the iron ions move away from the iron in the soil. Continuous corrosion of the iron occurs as the current flows continuously. The movement of positive ions toward the copper surface provides the copper with protection against corrosion. We now have a galvanic cell or battery. The iron is corroding with iron ions flowing from it into the soil. The iron surface is called the anode of the cell. The copper, which is receiving corrosion protection, is the cathode. These two terms, anode and cathode, are helpful for discussing and understanding corrosion.

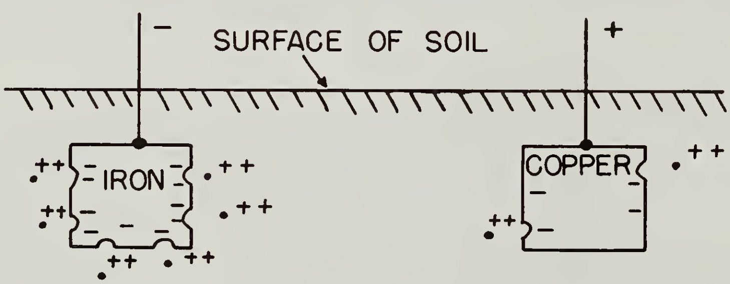

Fig. 2. Potential difference due to activity of dissimilar metals.

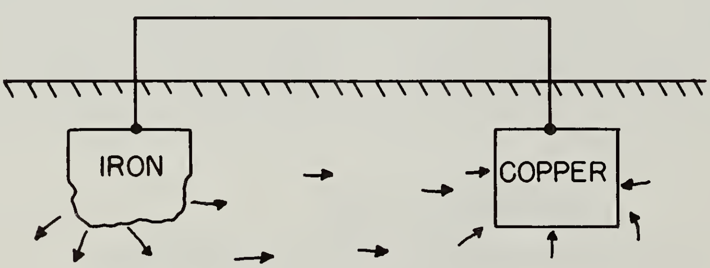

Fig. 3. Flow of currents (movement of positive charge) between dissimilar metals.*

*Note: Throughout this bulletin, arrows representing current are drawn to show the movement of positive charge. To show the direction of electron flow in metallic conductors, arrows should be reversed.

- An anode is a metal surface at which the current (movement of positive charge) is from metal into soil. To be an anode means corrosion, for most metals.

- A cathode is the surface at which the current (movement of positive charge) is from soil into the metal. To be a cathode usually means protection against corrosion.

Four types of dissimilarities are particularly important in causing underground corrosion on electric systems:

1. Dissimilar metals (copper and steel) in grounding networks. Dissimilar metal couples such as shown in Fig. 3 are present in practically all electrical grounding networks. An illustration showing corrosion of buried steel (an anchor rod) connected to the neutral conductor of a copper-grounded electric line is shown in Fig. 4. The anodic surfaces where corrosion occurs are on buried parts of the steel anchor assembly. The cathodic surfaces are copper grounding electrodes and ground wires.

   These copper-to-steel reactions are usually quite slow. However, in some soils, the corrosion has been significant and corrective measures have been necessary.

2. Differences in oxygen concentration. Another important dissimilarity is from variations in availability of oxygen to a metal surface. Fig. 5 shows a steel rod buried in soil and extending through the surface. In this situation, the soil near the surface contains more oxygen than is available at greater depths. Oxygen helps to form a film on the iron surface which makes the iron less subject to corrosion near the surface than deeper in the earth. These differences in oxygen concentration bring about movement of ions and corrosion as shown in Fig. 5.

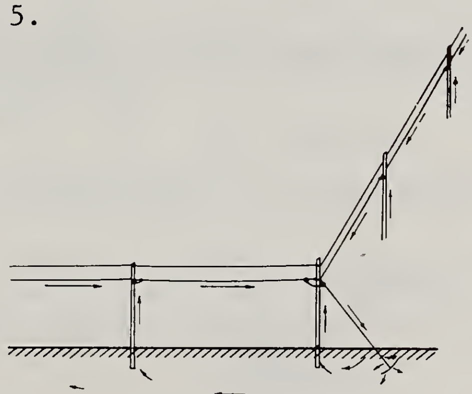

Fig. 4. Direct currents (movement of positive charge) between copper grounds and a steel anchor.

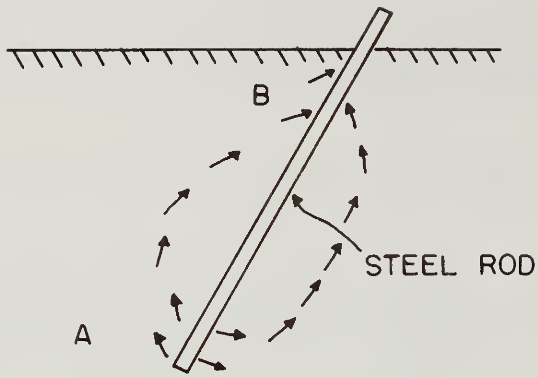

Fig. 5. Corrosion from differences in oxygen concentration.
(A) Unaerated soil, oxygen lacking, metal surface corroding.
(B) Aerated soil, oxygen present, metal surface protected.

3. Dissimilar surfaces of same kind of metal. A third kind of dissimilarity is from variations in the metal surface. This may happen, for example, if a black anchor is connected to a galvanized or bright anchor rod. The anchor is rolled steel with an oxide surface beneath the black paint. This oxide film is less active chemically than the zinc or bright iron surface of the anchor rod. Thus, the metal surface of the anchor is protected while that of the anchor rod is corroding. The corrosion and the movement of ions are shown in Fig. 6. We should note that in both Figs. 5 and 6, the corrosion occurs deep in the ground.

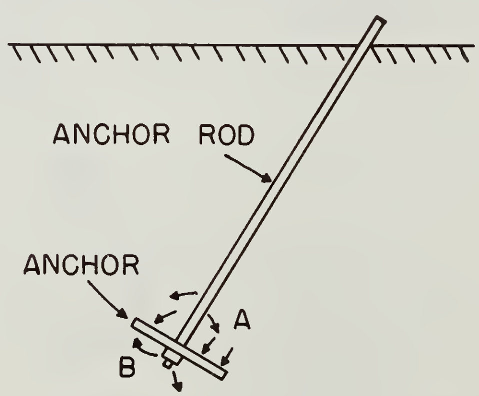

Fig. 6. Corrosion from differences in metal surfaces.
(A) Bright steel or galvanized anchor rod, metal surface corroding.
(B) Oxide-coated black anchor plate, metal surface protected.

4. Soil variations. Soil characteristics may vary widely over the areas traversed by an electric line. For example, locations of an electric line are shown in Fig. 7 as on a detail map. The shaded areas represent locations of corrosive soils such as alkali spots or marshy ground. Buried metals (ground rods, anchor rods and bare neutral or ground wires) corrode more actively in the shaded areas than in the unshaded areas. The flow of dc corrosion current is from metal to soil in the shaded (anodic) areas and from soil to metal in the unshaded (cathodic) areas. Note, however, that the return path for the direct current is via the electric neutral and ground conductors. The buried metals must be connected together by the electric neutral in order for these soil differences to take effect.

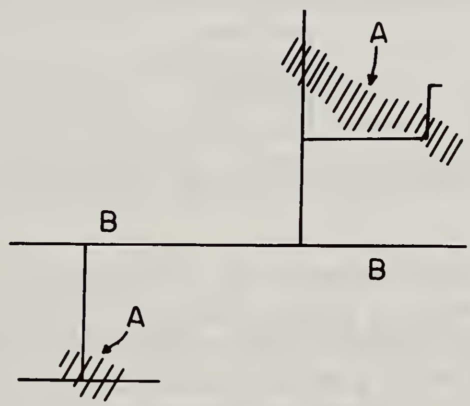

Fig. 7. Electric distribution system map shaded to show soil locations. (A) Corrosive soils, buried metal corroding. (B) Less corrosive soils, buried metal protected.

To summarize, underground corrosion is due largely to dissimilarities or variations in the metal and in its environment. These are: dissimilar metals such as copper and steel, variations in oxygen concentration, variations in the surface such as bright and oxide-coated iron, and soil variations over larger geographic areas. All of these variations can and do contribute to corrosion.

ELECTRICAL MEASUREMENTS FOR CORROSION TESTING

Electrical measurements are used for corrosion testing and surveys to determine what is happening to metal in the ground. These measurements deal with dc voltages and currents, not with the ac voltages and currents resulting from operation of the electric system.

Dc Voltage or Potential

The most often used measurement in corrosion testing is the dc potential (voltage) measurement. Potential can be pictured as electrical pressure that causes current to flow if it has a path to follow.

Looking back at Fig. 2, how would you measure the potential (voltage) of the iron or copper in the soil? To measure potential requires a voltmeter as shown in Fig. 8. One meter test lead is connected to the iron or copper. But, how shall the other lead be connected to the earth? If we touch the ground with the end of the lead or metal attached to it, this metal also will assume a potential that depends on the type of metal and the kind of soil.

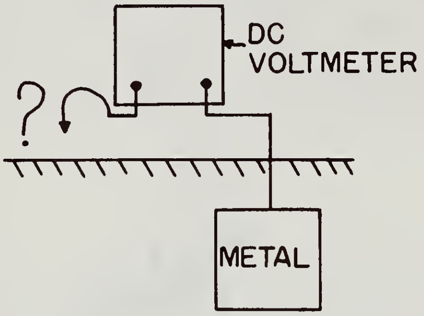

Fig. 8. Voltmeter connected to buried metal for a potential measurement.

For reliable potential measurements in underground corrosion testing, the corrosion investigator uses a copper-copper sulfate half cell, as shown in Fig. 9. This half cell consists of a copper rod surrounded by a saturated copper sulfate solution with a porous plug at the bottom to allow solution contact with the earth. The copper-copper sulfate half cell has a dc potential which is practically constant for a wide variety of conditions. Therefore, the copper-copper sulfate half cell is a good reference for dc potential measurements of metal structures in soil. Using the half cell, connections for the potential measurement can be completed as shown in Fig. 10.

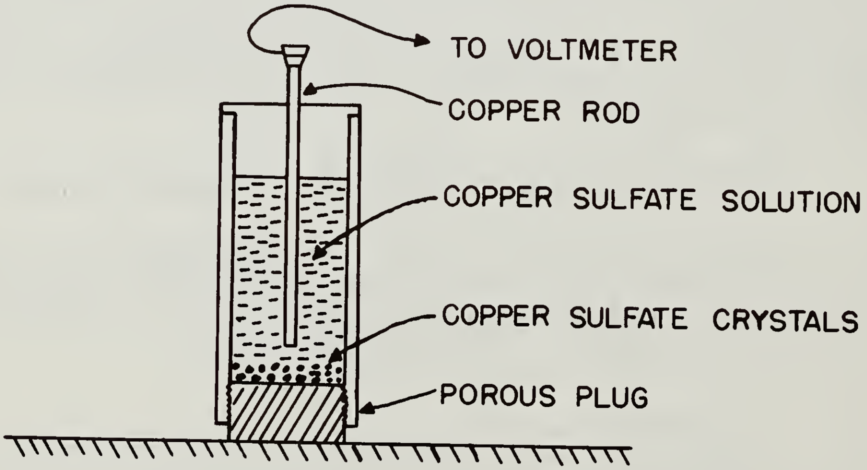

Fig. 9. Copper-copper sulfate half cell.

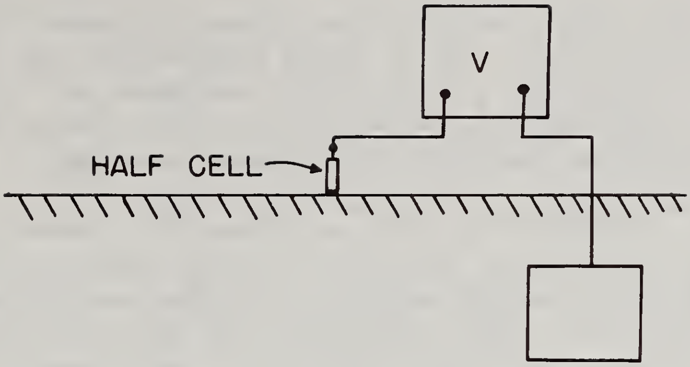

Fig. 10. Connections for measuring potential of a metal in soil.

Suggested Experiments with dc Potential Measurements

To understand information about underground corrosion requires more than reading, listening, and observing. It requires "on-the-job" experience which includes field testing, efforts to interpret, and excavations for visual checks to see what is going on. We urge you to try some of the experiments or tests which will be described.

Experiment No. 1

The first experiment can be performed indoors with materials and apparatus as follows:

- A dc voltmeter, with full-scale reading of approximately 2.5 volts or less and sensitivity of at least 20,000 ohms per volt. (A meter with a 1 megohm input resistance or higher is more desirable, if available.) Fig. 11 shows a dc meter with full-scale range of one volt.

- A copper-copper sulfate half cell.

- Specimens of copper, iron and carbon. A stub of No. 6 AWG copper wire, a large bright (not galvanized) iron nail and a galvanized nail or other small galvanized object make good specimens. For carbon, use the center rod electrode of an old flashlight battery or a short piece of underground cable with neutral wires removed and the carbon-filled insulation shield in contact with the soil.

- Moist soil, approximately 5 kg (11 pounds), packed in a plastic or plastic-lined container.

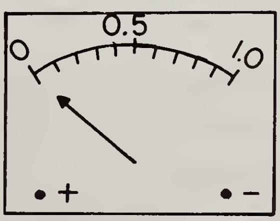

Fig. 11. Dc voltmeter for potential measurements.

Pack the soil firmly into the container and around the specimens as they are inserted. For best results, try to avoid disturbing the specimens when measurements are being made. Locate the specimens at intervals along the perimeter of the container and leave space in the center for placing the half cell several inches away from the nearest specimen.

Measure the half cell potentials of your specimens by connecting the meter as shown in Fig. 12. Potentials that you are likely to measure are listed in Table I. The most active materials at the top of the list have the most negative potentials. The potentials will vary with the kind of metal, corrosiveness of soil and condition of the metal surface (bright, dull, or rusty).

Measure the potentials of your specimens and enter them in the space provided in Table I.

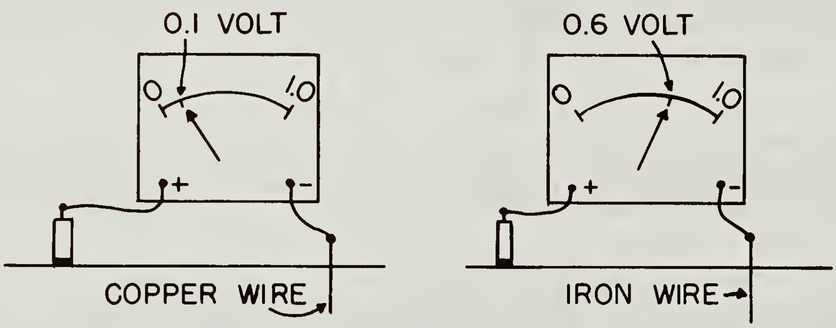

Fig. 12. Potentials from a copper-copper sulfate half cell of copper wire and iron wire.

Table I.

Potentials Measured from a Copper-Copper Sulfate Half Cell

Buried Metal or Material	Potential: Probable Potential (volt)	Potential: Experiment No. 1 (volt)
Zinc or new galvanized steel	-1.1	
Steel or iron	-0.5 to -0.7	
Copper	-0.1	
Carbon (after several hours or days	0 to +0.3	

Any two metals shown in Table I can be connected together to form a galvanic cell. The metal that is higher in the table will be the anode and corrode while the metal lower on the table will be the cathode and be protected. One familiar example of a galvanic cell is a flashlight battery. Carbon and zinc are the electrodes. Placed in a suitable electrolyte, carbon and zinc have a potential difference of approximately 1.6 volts, 0.2 volts greater than would be suggested by Table I.

Using the information given in Table I, you should be able to determine the dc voltage between any two specimens, the direction of current flow if they are connected together, and which metal will corrode in any combination of the metals. Try doing this, first from the observation listed in Table I and then by connecting the voltmeter to any two specimens.

Polarizing Films

By now you may be wondering why there isn't serious corrosion underground in most electrical grounding networks. The rule for safe grounding is to connect everything solidly together. On a common-neutral multi-grounded system, the electric neutral, usually grounded with copper electrodes, is connected to underground piping, tanks, well casings, anchor guys, frames of machines, and steel piling under buildings housing heavy equipment. At a generating station, there are large quantities of buried copper, a maze of underground piling, and the station itself may be supported on steel piling. All of these are usually connected solidly together for safety and electrical protection.

In spite of these apparently adverse conditions, underground corrosion usually has not been serious. This is because in most soils, polarizing films form on metal surfaces in such a manner that the currents and the rate of corrosion soon drop to quite low values.

Experiment No. 2

A small-scale model will help to show how polarizing films influence underground corrosion where buried copper and steel are connected together. The materials needed are those listed in the first experiment with a few additional items as follows:

- Three copper specimens, stubs of No. 6 AWG solid copper conductor approximately 15 cm or six inches long.

- An iron or steel specimen (a large spike or stub of ungalvanized iron wire) such that the surface area touching the soil will be approximately the same as for one copper stub.

- Three or four small insulated wires with alligator clips at both ends, to make connections between specimens.

For best results, make certain that the soil is moist, free of trash and pebbles, and firmly compacted.

a. Insert all three of the copper specimens along one side of the container, five to eight centimeters (2 to 3 inches) apart. Insert the steel (or iron) specimen near the opposite side of the container. Leave space in the center for the half cell, which should be placed approximately mid-way between the specimens. Smooth and repack the soil. The arrangement should be approximately as shown in Fig. 13.

b. Measure potentials of the individual stubs. Then connect the three copper stubs to each other with two of the small wires with alligator clips.

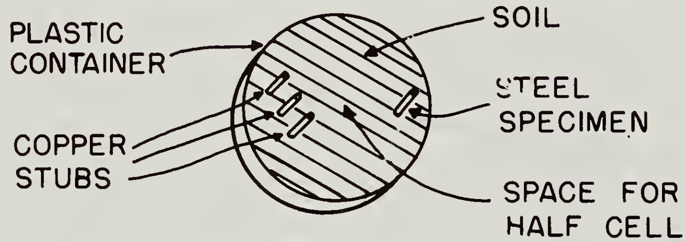

Fig. 13. Arrangement of specimens for polarization test.

c. Connect the "-" meter terminal to the three stubs of copper wire and "+" terminal to the half cell. Place the porous plug of the half cell against the soil surface. Observe the potential and write it in the second column of Table II beside the 0.1 figure.

d. Disconnect the negative meter lead from the copper stubs and connect it to the iron (or steel) specimen. Complete the potential reading and write the potential in the fourth column of Table II, beside the -0.6 value.

Note that the remaining observations for Experiment No. 2 to be recorded on Table II start immediately when the connections for the next step are completed. Avoid disturbing specimens during the test. Any movement will admit oxygen into the soil and cause surfaces to depolarize.

e. Note that the meter is connected and indicating the potential of the steel specimen (step d).

f. While one person watches the meter, connect the steel specimen to the copper specimens as shown in Fig. 14. Observe voltage immediately, then at intervals as shown in Table II. Write the observed potentials beside those shown in the table.

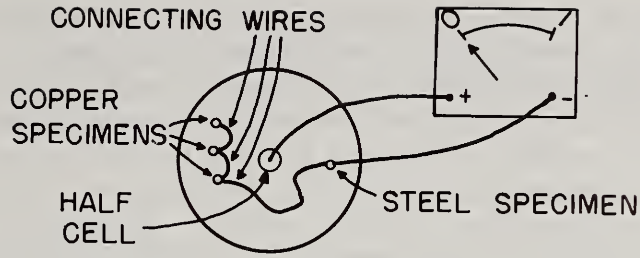

Fig. 14. Connections to specimens for polarization test.

Table II.

Potentials of Stubs of Wire Measured from a
Copper-Copper Sulfate Half Cell

POTENTIAL						
Copper Stubs		Iron or Steel Stubs		Copper & Steel Stubs		Condition and Time
Probable Potential (volt)	Experiment No. 2 (volt)	Probable Potential (volt)	Experiment No. 2 (volt)	Probable Potential (volt)	Experiment No. 2 (volt)	
-0.1		-0.6				Measured separately
				-0.38		When connected
				-0.43		15 seconds later
				-0.46		1 minute after connecting
				-0.50		5 minutes after connecting
				-0.51		30 minutes after connecting
				-0.55		4 days after connecting

The proportions of copper and steel used in developing Table II (three times as much copper as steel) may occur along a rural electric line with copper grounding and steel anchors connected to the neutral.

The consequences of cathodic polarization films (films forming on the cathodic copper surface) such as indicated in Table II are far-reaching. One result is that the corrosion of buried steel connected to copper grounds is usually at such slow rates that the corrosion is insignificant or is accepted as normal corrosion of the buried steel. The second result is that copper is receiving important amounts of cathodic protection even though the flow of current is quite small. In Table II, the figures in the "probable" columns indicate that the copper potential after 4 days was 0.45 volt more negative than it was by itself, before connecting to the steel stub.

Potentials of Ground Connections and the Neutral of an Electric Line

The relationships we have just seen help to explain some of the peculiar things that sometimes occur in underground corrosion. Polarization films such as evidenced in Table II often provide an explanation. Polarization behavior of buried metals is important and should be considered when deciding on corrective measures against underground corrosion.

For more experiments, use a voltmeter and half cell to measure and record potentials of the neutral along electric lines. For a copper specimen, find a copper "butt wrap" ground that has been disconnected from the neutral for a few weeks. A broken ground wire may provide the opportunity. (Don't use a driven ground; the rod probably has a bare steel tip.) For a steel specimen, use an old insulated guy-anchor assembly (from which the galvanizing has disappeared) or a steel fence post.

The dc neutral potentials along an overhead pole line will show the effects of all the materials connected to the neutral. Potentials vary with the type of soil and with the proportions of copper and steel connected to the neutral within a mile or so. The potential is likely to be less negative near locations where underground cables are installed. Potentials will probably be more negative near many services because of greater amounts of buried steel in anchor assemblies and on the consumer's premises.

DEMONSTRATION OF DISSIMILAR METALS

The demonstration that follows can be used practically anywhere, at home if you wish. The materials needed are some clear water glasses, specimens of copper, iron, and zinc such as were used in the previous experiments, short jumpers with alligator clips, and water to put into the glasses. For best results, lightly sand or scrape the iron and copper surfaces they are uniform and bright. The same should be done to the zinc or galvanized specimens, but don't scrape off all of the galvanizing.

Place the specimens in glasses as follows: In one glass, an iron specimen by itself; in another, iron and copper connected together; in a third glass, iron and zinc connected together; in a fourth glass, iron, copper and zinc connected together. Specimens in each glass should be connected as shown in Fig. 15. Then fill the glasses with water. Ordinary tap water will do. For faster results, mix salt with the water in a pitcher and stir until it is dissolved before pouring the water in glasses.

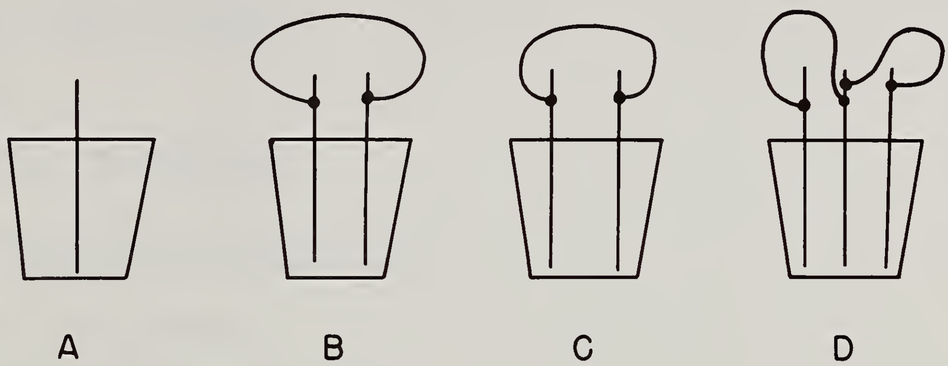

Fig. 15. Specimens in water to demonstrate dissimilar-metal effects; (A) iron; (B) iron and copper; (C) iron and zinc (or galvanized); (D) iron, zinc and copper.

Results of this demonstration should be visible within an hour or two. A brown stain in the water shows as iron begins to rust. Some stain will appear around the iron nail by itself (Fig. 15A). The stain appears more rapidly in the glass with iron and copper connected together (Fig. 15B). In Figures 15C and 15D, where the water stays clear or slightly cloudy with no rust stain, the iron is being protected against corrosion. The corroding zinc forms white corrosion products that cloud the water and, in time, accumulate at the bottom.

In this introduction, we have endeavored to make corrosion more understandable and to describe some of the tests that are used in corrosion surveys. To learn more about underground corrosion, try some of the demonstrations and experiments that have been described. Then, study other parts of this bulletin and articles about corrosion. Third, gain experience by performing tests and trying out corrective measures. Finally, ask questions and discuss your observations with others whenever there is an opportunity.

MANUAL ON UNDERGROUND CORROSION CONTROL IN RURAL ELECTRIC SYSTEMS

PART III. TESTING AND SURVEYS

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PART III. TESTING AND SURVEYS

Corrosion testing and surveys are performed mostly by measuring dc voltages, currents and resistances. Measurements that will be discussed here are of:

1. Electric dc currents, representing

    a. Rates of corrosion of buried metals
    b. Amount of protection, by a sacrificial anode or rectifier

2. Dc potentials (voltages) indicating

    a. Probable corrosion or protection against corrosion
    b. Direction and/or amount of dc current between locations where neutral potentials differ

3. Resistance-to-earth of grounds or of the electric neutral

4. Earth resistivity

SEEING THE LARGER PICTURE

Each measurement during corrosion testing reveals only one part of a picture. Usually, a number of measurements are needed to show what is happening. For example, if we could observe dc currents where bare neutrals of underground cable are corroding, they might be as shown in Fig. 1. Positive ions representing loss of metal are moving from metal into the soil. Soil characteristics at this location must have something to do with the corrosion, but we see only a part of what is happening.

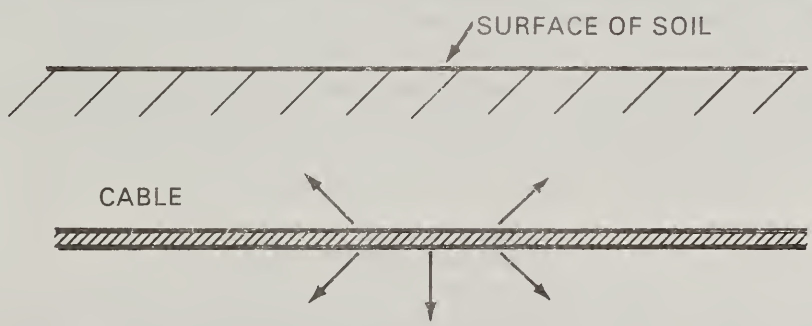


Fig. 1. Dc (movement of positive ions) where cable neutral wires are corroding

Looking at a longer length of the cable in Fig. 2, we see a flow of direct current back to the cable neutrals at B. The circuit is completed through the cable neutral wires. Now we see the effects of soil differences which are usually important in causing corrosion. Also, we begin to get ideas for using sacrificial anodes to relieve the corrosion.

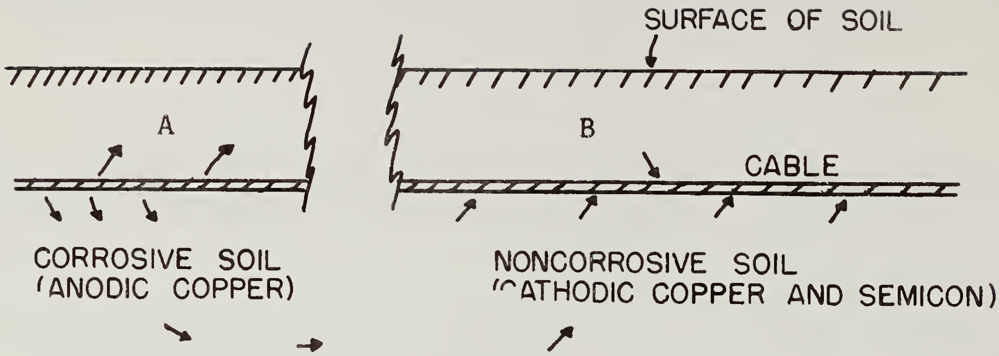


Fig. 2. Dc (movement of positive ions) near underground cable. (A) Anodic area, neutral wires corroding. (B) Cathodic area, neutral wires protected.

For a wider perspective, consider what happens where the underground cable is connected to an overhead pole line. Dc along the neutral and in the earth may be as shown in Fig. 3. In this example, dc is flowing along the cable neutral toward the terminal pole. The current is flowing down the cable terminal pole guy, indicating corrosion of anchor rod and anchor. However, most of the dc continues along the pole line neutral. Corrosion can be expected wherever the dc returns to earth. We need to be concerned about what is happening elsewhere where the dc returns to earth as well as at the cable terminal pole.

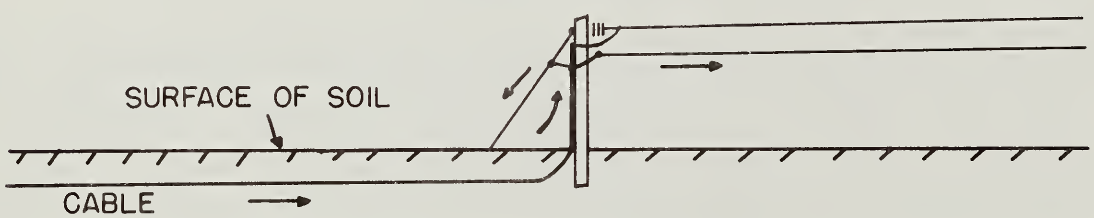


Fig. 3. Direct currents (movement of positive charge) along the electric neutral and guy at a riser pole.

The electric neutral and ground connections behave as a huge galvanic cell. We should try to see the whole, as well as the parts, during corrosion tests and in interpreting results.

PRECAUTIONS

When connecting a test instrument to the neutral, the possibility of abnormal ac voltages should always be recognized. To minimize possible hazards, the following are suggested:

1. Instruct test crews about possible abnormal conditions and symptoms to watch for.

2. If ac voltages are suspected, check first with an ac voltmeter connected to the neutral and an auxiliary ground such as a large screw-driver.

3. Place the test instrument on the ground before connecting, and follow the "one hand" rule (touch metal and leads with one hand only) when making connections.

4. To avoid damage to the test meter, leave meter switch in "off" or "short" position while connecting. Then watch for "fuzzing" of the pointer or erratic behavior which would indicate presence of abnormal ac voltages as a multi-range meter is switched through its higher ranges.

DIRECT CURRENT MEASUREMENTS

It is possible in some situations to measure direct currents to determine the rate of underground corrosion. The measured dc represents the movement of metal ions into the soil. From the weight of an ion and the charge carried by each ion, we can calculate the weight loss per year in grams or pounds. For iron, this calculated weight loss is 9 kg (20 pounds) per year per ampere dc, or 0.45 kg (one pound) per year for a steady current of 50 mA.

Two practical difficulties arise in making dc current measurements in electric grounds and neutrals.

1. In many cases, it is difficult or not possible to connect an ammeter into the dc circuit where the measurement is desired. This is true, for example, in Figs. 1 and 2.

2. Even where a dc ammeter could be connected, it is usually inconvenient and may be hazardous to connect a dc ammeter in series with the neutral or ground conductor of an energized electrical circuit.

The difficulties can usually be overcome by using a sensitive dc voltmeter to measure voltage drop along a length of conductor. This measurement as usually made requires a very sensitive dc voltmeter, one that reads to the nearest micro-volt (millionth of a volt). Special test clamps with high contact pressure are needed for connecting to the guys to avoid error due to contact potentials. A meter with test leads and clamps for this measurement is shown in Fig. 4. The meter that is shown has a sensitivity of either 0.2 or 1 mV full scale, with 100 scale divisions. For 100 scale divisions and 1 mV full scale, each division on the scale represents 0.01 mV or 10 microvolts. A pointer-type meter with sensitivity of 2 mV full scale has also been found to be satisfactory for this measurement.

Fig. 5 shows a calibration chart for translating voltage drop readings into currents in some common types of guy strand and copper conductors. Vertical lines on the chart are at 10 microvolt (.00001 volt) intervals, which are the same as the millivoltmeter scale divisions if the meter has 100 scale divisions and a sensitivity of 1 mV for full scale deflection. Thus, for a reading of four scale divisions (40 microvolts) and 3/8-inch Siemens-Martin guy strand, the guy current is 6 mA.

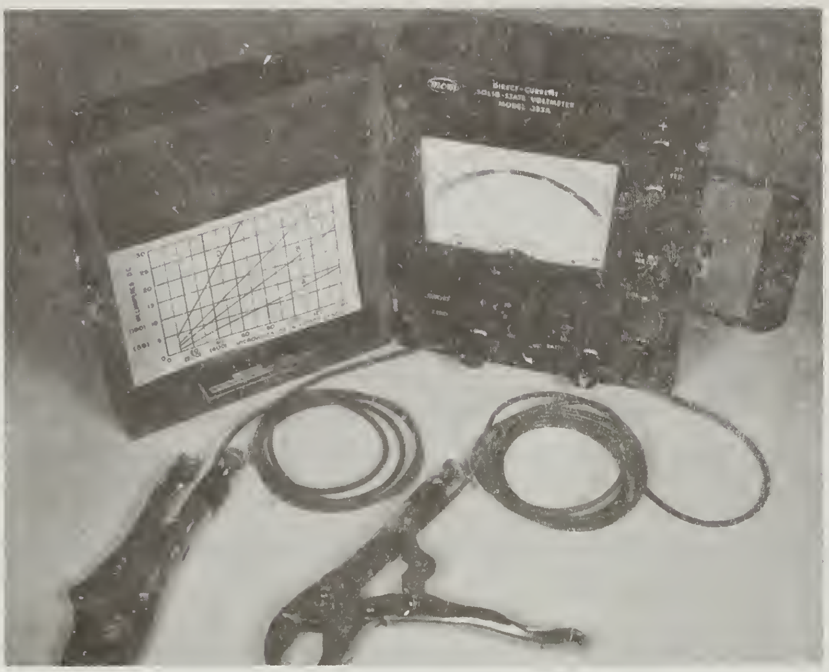


Fig. 4. Millivoltmeter, leads and test clamps for voltage drop determination of direct current in a guy or other conductor.

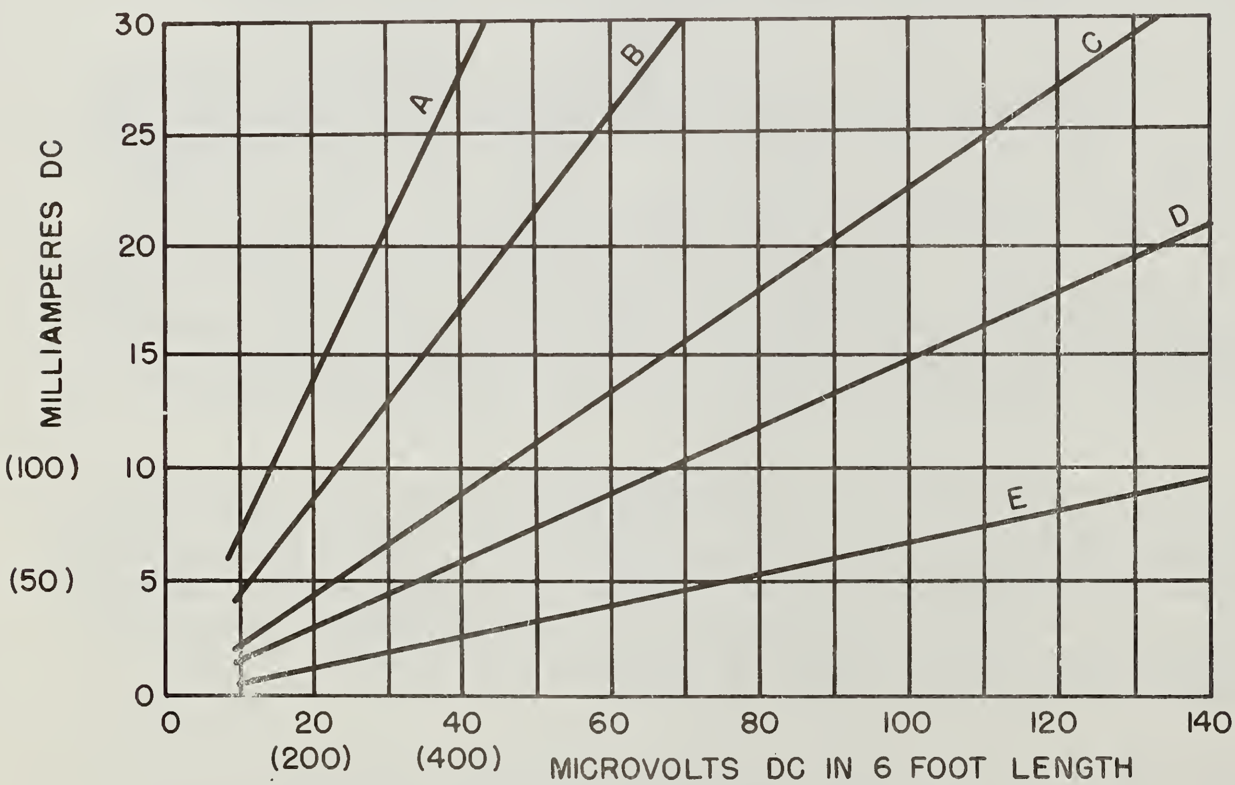


Fig. 5. Sample calibrations for voltage drop determinations of currents in Siemens-Martin guy strand and soft-drawn copper conductor. (A) No. 4 AWG Copper. (B) No. 6 AWG Copper. (C) 7/16" Guy Strand. (D) 3/8" Guy Strand. (E) $\frac{1}{4}$" Guy Strand.

The current calibrations will differ for other types of steel strand. High-strength strand generally has higher resistance than Siemens-Martin guy strand. Calibration for these or other materials requires a dc source, which may be a battery in series with a resistor, and a milliammeter for observing the current. For example, a 12 volt battery with a 1000 ohm resistor in series would provide a current of .012 A (12 mA). For guy strand of unknown resistance, take a length of the guy and connect the millivoltmeter across the six-foot length. Connect the dc source and observe the voltage drop and current.

From Fig. 5, a 12 mA current in 7/16" Siemens-Martin guy strand would result in a 52 microvolt drop. The same current in 3/8" strand would give a voltage drop of 68 microvolts in a 6-foot length. For a different type of strand (or other conductor), a calibration line can be drawn on the chart by plotting a single point and drawing a straight line through the zero intercept as was done for the other materials represented in Fig. 5.

The arrangement used for calibration is also valuable for training of people who are to do testing in the field. By impressing known amounts of dc in the shop, then having the observers determine the amount of dc from the millivoltmeter and chart, the accuracy of observations can be improved and mistakes avoided.

This measurement has the disadvantage of requiring a special voltmeter that may not be on hand unless purchased for this particular purpose. Present experience indicates that a meter with moving pointer may be preferable to a digital meter for this application. The voltages are very small for measuring in the field. At such low voltage ranges, the average reading is more easily seen with a pointer than with a digital read-out which may never reach a stable reading.

Direct Currents in Guys

Surveys of guy currents and anchor rod corrosion are usually made by means of voltage drop measurements as shown in Fig. 6. However, when measurement of guy currents is attempted for the first time, the first conclusion may be that the meter is not working. The following are suggested:

- If the millivoltmeter indicates "zero," make certain the range setting is correct; then check for continuity of test leads and clamps by gripping one clamp in each hand, moistening hands if necessary. Movement of the pointer indicates that leads are continuous. (The actual reading may be zero on many guys.)

- If the indication is erratic or near zero, remove the top test clamp and reconnect it to the guy immediately beside the lower clamp. The pointer should drop to or near zero. If it does not, check for poor connections in the leads and test clamps. Measurements up to 10 microvolts (one scale division) may result from normal contact potentials and should be disregarded.

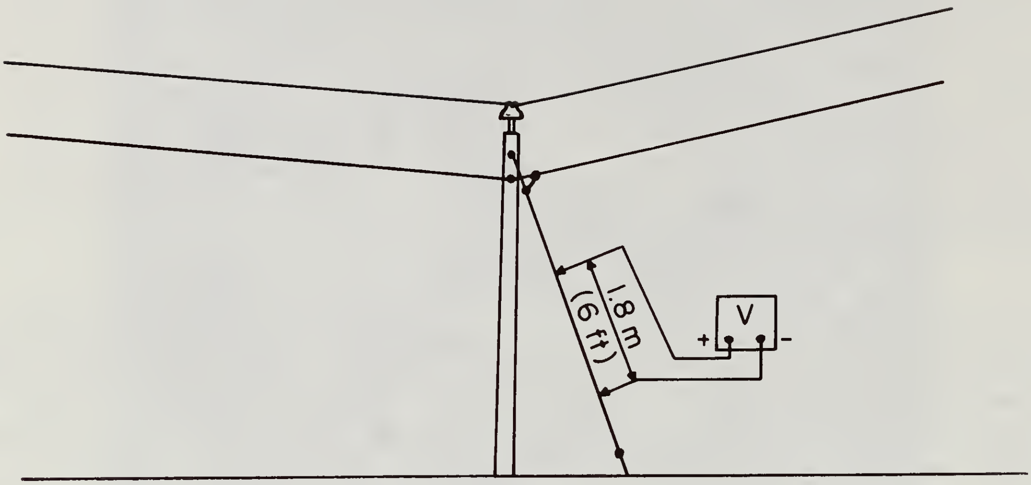


Fig. 6. Connections for measuring voltage drop
to estimate the flow of dc in a guy.

The dc current in a guy indicates the rate of anchor and anchor rod corrosion at the time of the measurement. The corrosion rate of steel as related to the measured current toward ground is 9 kg (20 lb) per ampere year or 0.45 kg (1 pound) for each 50 milliamperes flowing steadily for one year. This is based on the atomic weight of iron and a valence of 2 in the initial corrosion reaction. Guy currents are usually at their highest in summer months, perhaps twice their year-round average in the northern states. Guy current measurements (where anchor rods failed or were nearly corroded off) have indicated that failure is likely where milliamperes (in summer) multiplied by years in service equals 100 to 200. Thus, 5 mA dc in a guy would indicate probable failure in 20 to 40 years; 40 mA in $2\frac{1}{2}$ to 5 years.

Figure 7 shows the distribution of guy currents measured on an electric distribution system in South Dakota. Note that most of the observed guy currents are 5 mA or less, indicating slow or negligible corrosion. Relatively few are above 20 mA, indicating very rapid corrosion. These observations were made in an area of relatively severe anchor rod corrosion. Where anchor rod corrosion has not been a problem, guy currents are sometimes so small that this type of measurement may have little value.

Dc in Neutral and Ground Wires

Voltage-drop observations have been found convenient for a variety of dc current measurements, where the current is known to be flowing in a ground wire or connecting wire that is accessible along a length of a foot or more. A length shorter than 1.8 m (6 ft) means less current sensitivity so that a multiplier or correction is necessary in using the calibration chart, Fig. 5.

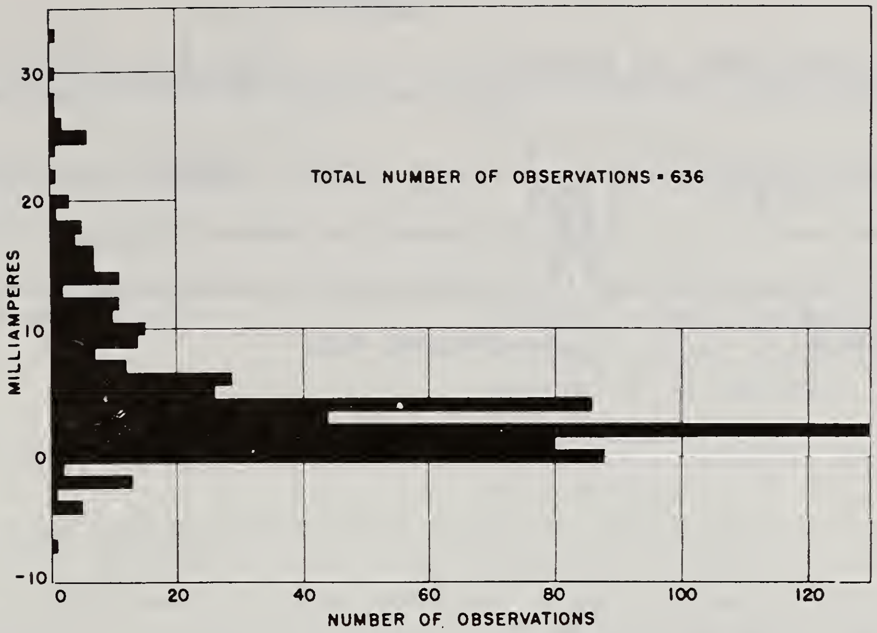


Fig. 7. Distribution of galvanic currents in guys. Positive values indicate dc (movement of positive charge) toward the anchor rods.

DC POTENTIAL MEASUREMENTS

Dc potential (voltage) measurements have the advantage of being easy and inexpensive, but they may be difficult to interpret. As experience is gained, the meaning of the potentials becomes more clear.

Introductory discussions of dc potential measurements and of the copper-copper sulfate half cell are given in Part II, Introduction to Corrosion. For one not familiar with this subject, a review of the section on potential measurements is suggested.

In discussions that follow, the terms "potential" and "half-cell potential" mean dc potential to a copper-copper sulfate half cell.

Underground Electric Facilities

Dc potential measurements are widely used on underground systems, to minimize the necessity for costly excavations and visual checking for corrosion. Dc current measurements are often not feasible even though the measured currents would often give more reliable indications of the corrosion activity.

A typical connection for measuring dc potential of an underground cable neutral is shown in Fig. 8.

If the potential meter has only one connecting lead (meter and half cell are one unit), connect the lead to the cable neutral or grounded enclosure.

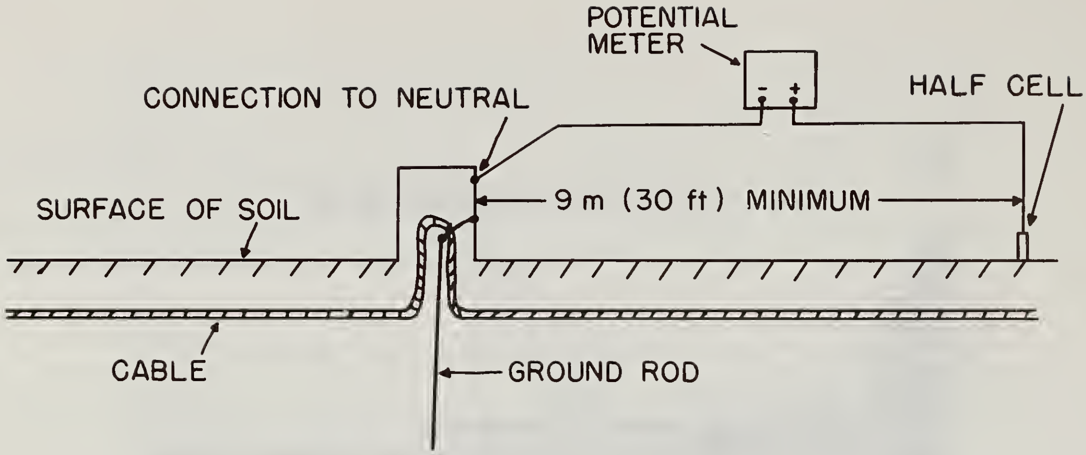


Fig. 8. Measurement of cable neutral wire potential

When a separate potential meter and half cell are used, the normal connection is as shown in Fig. 8. The negative terminal of the meter is connected to the neutral and the positive terminal is connected to the half cell. Upscale readings on the meter are recorded as negative (-) since the neutral is more negative than the half cell. If the meter pointer moves backward off the scale, reverse connections and make certain that the voltage is recorded as positive (for example +0.05). A meter with offset zero or center zero will indicate a positive reading (left of zero) without the need for reversing connections.

Place the half cell over the cable at a location 9 meters (30 ft) or more distant from any steel ground rod, anchor assembly or anode connection to the neutral. (If in doubt, use a longer connecting lead and move out farther along the cable.)

Note that the connection for this measurement may be made to the outside of the enclosure, assuming it is effectively connected to the neutral and <u>if</u> an effective contact such as on the bright pentahead bolt is possible. If in doubt, connect directly to the neutral inside the cabinet. A direct connection to the neutral is particularly helpful (a) to verify a "zero" reading, or (b) if the cabinet itself is in contact with soil.

Sample potential readings and inferences that might be drawn from the readings are given in Table I.

<u>The long test lead for potential surveys</u>: Dc potential measurements can be performed with a long test lead so that the half cell is placed over the cable at distances up to 0.4 km (1/4 mile) or more from the connection to the neutral. This permits measurement of potentials or potential profiles even where the cable is not accessible without digging.

TABLE I.

Meaning of Dc Neutral Potentials of the Underground Cable Neutral

Potential from a Copper-Copper Sulfate Half Cell (volts)	Condition of Copper Cable Neutral Wires
-0.5 or more negative	Copper is well protected. Indicates that steel is connected to neutral.
-0.25 or more negative	Not being corroded, in most soils.
-0.10 or less negative	May be corroding.
0 or positive	Probably corroding. Dig and check.

Fig. 9 shows the measuring circuit when a long test lead is used for dc potential measurements. The potential desired is that of the cable neutral wires at A. It could be measured directly by excavating and connecting the potential meter to wires at that point. With connections as shown in the figure, the measurement is via the cable neutral wires from A to B. Probable sources of error are:

a. Any direct currents flowing along the neutral wires between A and B will cause an IR drop that becomes part of the dc potential indicated by the meter.

b. If the neutrals have been severed due to corrosion at any location between A and B, there is no continuous metallic connection. The indicated potential will be that of the neutral wires before the separation, not at A.

c. The metal enclosure may not be effectively connected to the neutral. (To minimize error, connect directly to neutral inside the enclosure.)

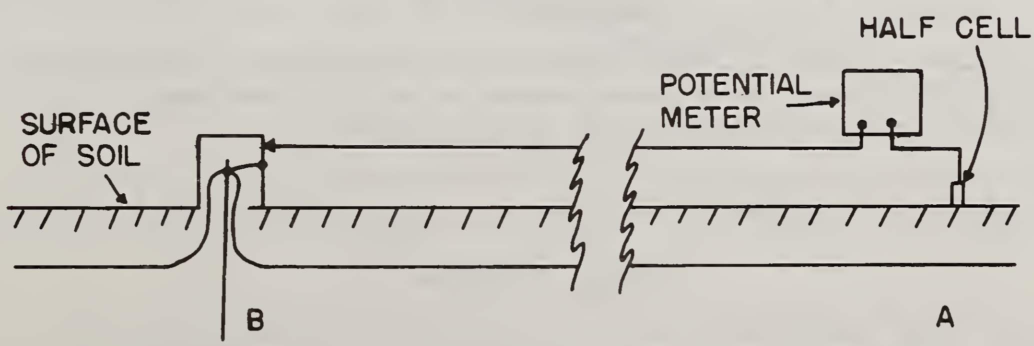


Fig. 9. Potential measurement using a long test lead.

Resistance of the long test lead presents no difficulty because it is low compared with that of the potential meter. For example, if the test lead has a resistance of 25 ohms and the potential meter has a resistance of 10 megohms, the effect of the lead resistance is inconsequential. However, weight and bulk of the test lead may become a significant factor in measuring at distances greater than 0.4 km (1/4 mile).

Fig. 10 shows a sample of potential profile data plotted against distance along the cable, showing the effects of dc drop along the neutral wires. (Half-cell locations should be marked for this type of test so that the same locations will be used in both directions.)

Potential measurements perpendicular to the cable. Dc currents flowing to or from the cable at any location may be either anodic (from cable to soil), which signifies corrosion at that location, or cathodic (from soil to cable), which signifies protection against corrosion at that location. In either case, the net inflow or outflow of current results in a dc potential gradient along the surface of the soil at right angles to the cable, as shown in Fig. 11. The figure shows a method of observing the potential difference and direction of the current. Two copper-copper sulfate half cells are used. They should be checked first against each other to note and record any difference in potential when they are placed near each other. Then, one half cell is placed directly over the cable and the other is placed one or two meters to one side as shown in the figure. The value and the polarity of the potential difference are observed.

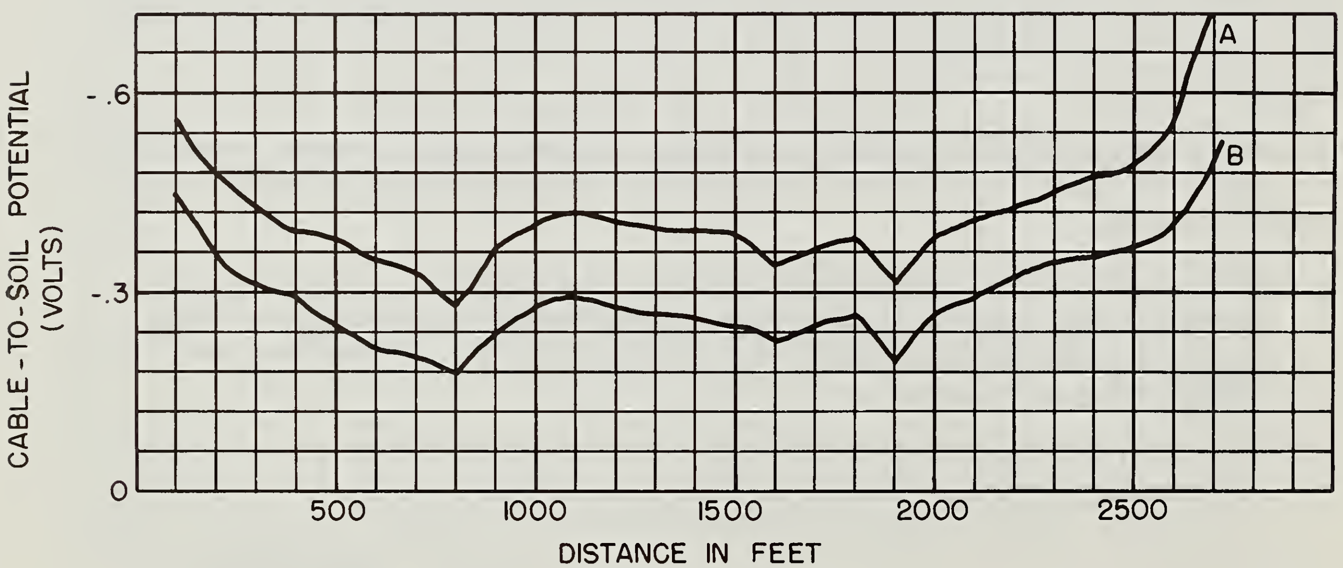


Fig. 10. Potential measurements with a long test lead, between two pedestals. (A) Connection to neutral at left pedestal; (B) Connection to neutral at right pedestal.

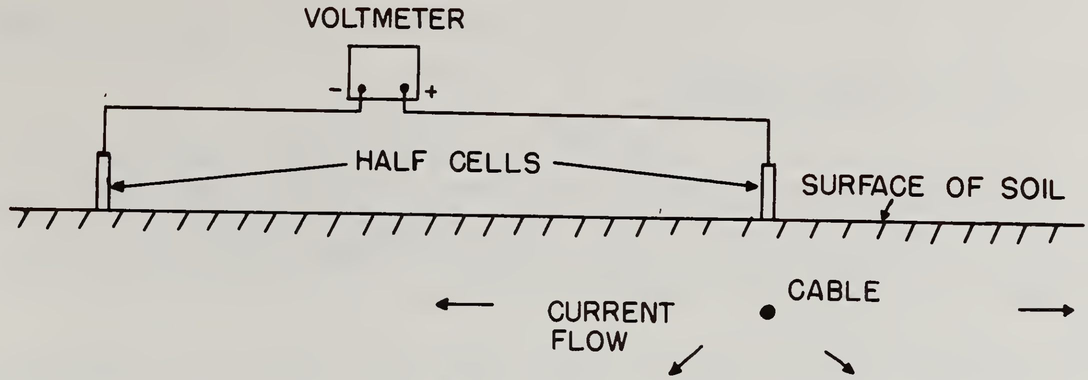


Fig. 11. Potential gradient due to anodic (corrosion) currents from underground cable neutral wires.

The potential gradient perpendicular to the cable may also be observed while taking "over the cable" potential measurements with the long test lead as already described. The sequence of steps at each test location is as follows:

a. Find the cable location with a cable locator.

b. Place the half cell directly over the cable.

c. Observe and record the potential.

d. Place the half cell the specified distance (such as 3 meters) off to the right of the cable. Observe and record the potential.

e. Place the half cell the same distance to the left of the cable. Observe and record the potential.

Sample observations of combined "over the cable" and "side" potential measurements are shown in Fig. 12. The potential differences are small, so it is helpful to have a sensitive potential meter that will indicate differences of .01 volt (10 millivolts) or less.

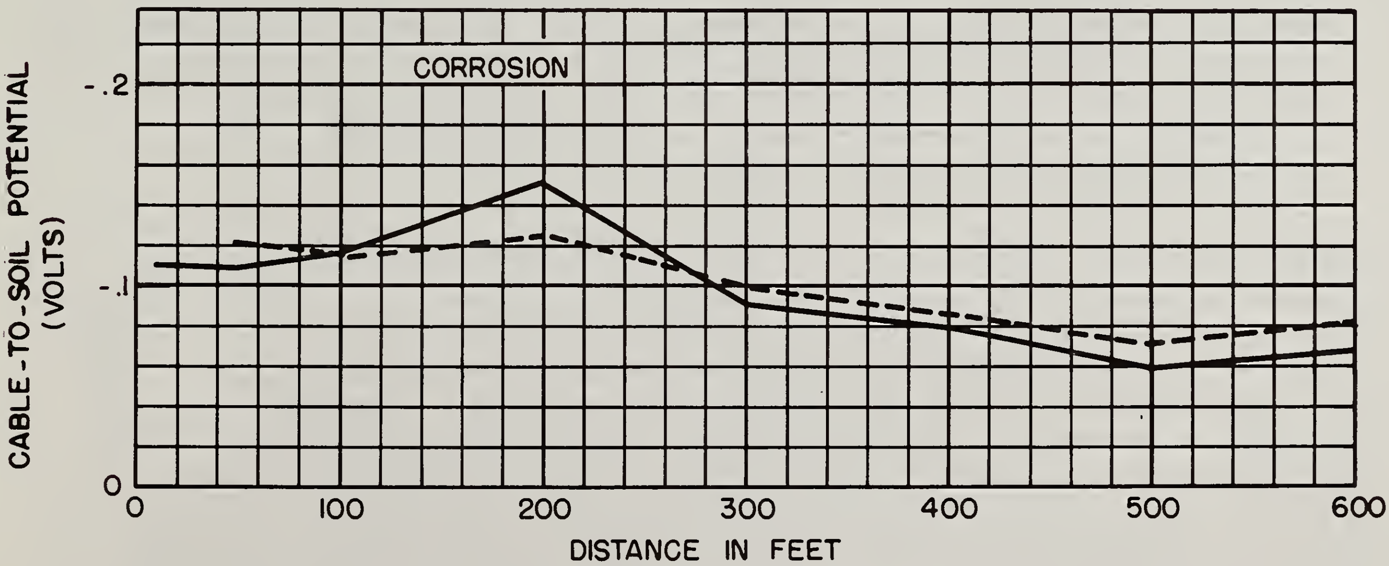


Fig. 12. Potential profiles with long test lead, including "side" measurements. Solid line is the potential with half cell placed over the cable. Dotted line is the potential with half cell 25 feet to one side of the cable. Anodic (corrosion) locations are indicated where solid line is more negative than dotted line.

Fig. 13 is a sample of a field data sheet including potential profile data.

Dc Potentials of Pole Line Neutrals

Half-cell potential measurements have not been very helpful for locating underground corrosion (such as anchor rod corrosion) along pole lines. A half-cell potential such as -0.5 or -0.7 volt can result from a variety of circumstances, so interpretation is difficult. Currents measured in guys or neutral conductors are much easier to interpret.

Dc pole line neutral potential measurements are helpful for the following purposes:

1. For determining the degree to which buried cable may be causing underground corrosion along the pole line. For example, buried steel connected to the neutral is more vulnerable to corrosion at -0.1 volt than at -0.5 volt.

2. To observe the direction and estimate the magnitude of direct current along the pole line neutral. As an example, assume dc potential readings as follows at Poles X and Y, separated by a distance of 100 m(328 ft). (The neutral conductivity is No. 6 AWG copper equivalent.)

   At Pole X, -0.35 volt
   At Pole Y, -0.29 volt (.06 volt difference)

   Using handbook values, we find that the copper neutral resistance is 0.136 ohms for 100 m (.413 ohms/1000 ft). The neutral current equals 0.06/0.136 or 0.441 ampere (441 mA).

   Direction of the dc (movement of positive charge) is from Pole Y toward Pole X, indicating probable underground corrosion at or beyond Pole X.

3. Half-cell potentials are helpful for identifying dc interference from pipeline protection rectifier systems or other dc sources. An extreme negative reading indicates current pick-up such as may occur near a rectifier anode bed. A positive reading may indicate an area of current discharge such as may occur near a protected pipeline. (For additional details, see Part V, Stray Current Corrosion.)

To interpret significance of the observed dc neutral potentials, departures from the norm for a particular line are usually more significant than the value of the observed potential. For example, the neutral of a rural electric line may be found to have an average half-cell potential of -0.4 to -0.7 volt. A relatively uniform potential along the neutral, anywhere within this range, is an indication of freedom from significant corrosion. A gradual shift to more negative potentials usually indicates anodic action (corrosion), either of a small structure (steel anchor assembly) that is experiencing rapid corrosion or of a large steel structure which may or may not be seriously affected, depending on its size. A shift toward a more positive potential indicates a cathodic area -- a relatively large amount of copper grounding, direct-buried cables, reinforcing steel embedded in new concrete or effects of a nearby pipeline that is under cathodic protection. Large positive potentials

Cooperative or Company:	CORROSION PROFILE DATA SHEET	Date:
Cable Size, no. Neutral wires, Phases:	Observers:	
Connection to the neutral at: pedestal 409		

HALF CELL LOCATION ALONG CABLE		OBSERVED POTENTIALS			EARTH RESISTIVITY		NEUTRAL-TO-EARTH RESISTANCE
Direction and Distance, ~~m~~ (ft)	At or Near	_m 10 ft Left	Over Cable	_m 10ft Right	5.2~~m~~(ft)depth		
		(volt)	(volt)	(volt)	(ohms)	(ohm-cm)	(ohms)
East 25 ft	Riser pole	-0.41	-0.38	-0.41	1.8	1800	0.5
50		- .40	- .38	- .39			
75		- .40	- .38	- .40			
100		- .39	- .36	- .38	2.6	2600	
125		- .37	- .34	- .37			
150		- .33	- .3	- .33			
175		- .3	- .28	- .33			
200		- .3	- .25	- .30	2.2	2200	
225		- .32	- .3	- .32			
250		- .37	- .34	- .37			
275		- .37	- .36	- .37			
300	Farm house	- .37	- .38	- .37	1.5	1500	0.4

Fig. 13. Sample data sheet including potential profile data.

such as +0.5 volt indicate stray current flowing toward a nearby protected structure such as a pipeline. In such situations, corrosion may be rapid. The owner of the rectifier should be promptly notified and immediate remedial action requested.

Steel and Iron Structures

Underground iron or steel pipes, tanks, wells, grounds and anchor assemblies will be found at many different potentials depending on soil and the condition of the metal surface. The half-cell potentials of such structures in soil, by themselves (not interconnected with others), may vary from values near zero for an old cast iron pipe, or -0.4 for an old steel pipe, rod or farm fence post with a rusty surface, to -0.7 volt or more negative for a new galvanized anchor assembly. At all of these potentials, corrosion may or may not be significant. Yet steel is regarded as vulnerable to corrosion at most of these potentials. This is an important inconsistency which may be stated as follows:

1. Buried iron and steel may have a long life at relatively positive potentials. In many applications, they provide the durability needed at such potentials.

2. To assure permanence of underground iron or steel structures, such as pipes and tanks, cathodic protection should be applied to maintain a potential of -0.85 volt or more negative to a copper-copper sulfate half cell. This criterion for protection is widely used for both bare and coated structures.

A large body of specialized experience is available on corrosion control and cathodic protection of underground steel structures. Where problems occur or are expected, a qualified consultant should be called upon. For best results, the corrosion specialist should be called upon at the time of design and prior to construction so that "built in" corrosion problems can be avoided.

ELECTRIC NEUTRAL RESISTANCE-TO-EARTH

A measurement of the overall (interconnected) neutral resistance-to-earth should be made if there is any question about the effectiveness of grounding. The measurement serves two purposes in neutral-wire corrosion surveys:

a. To help indicate whether neutral wires may have been severed, and

b. To indicate possible deterioration of grounds.

The neutral-to-earth resistance is measured with either a three-terminal or four-terminal ground tester, connected as shown in Fig. 14. Ideally, the distance from the cable to the test probes should be substantially longer than the dimensions of the ground electrode under test. This presents a problem when the electrode is the cable neutral which may be miles in length. Some trials have indicated that the distances shown in Fig. 6 give a reliable indication if there are no electrical grounds, buried cables, pipes or other buried conducting structures between the test probes and the cable. For greater accuracy of the measurements, the distances may be increased with proportions

approximately as shown in the figure until the indicated resistance no longer changes with distances between the cable and test probes.

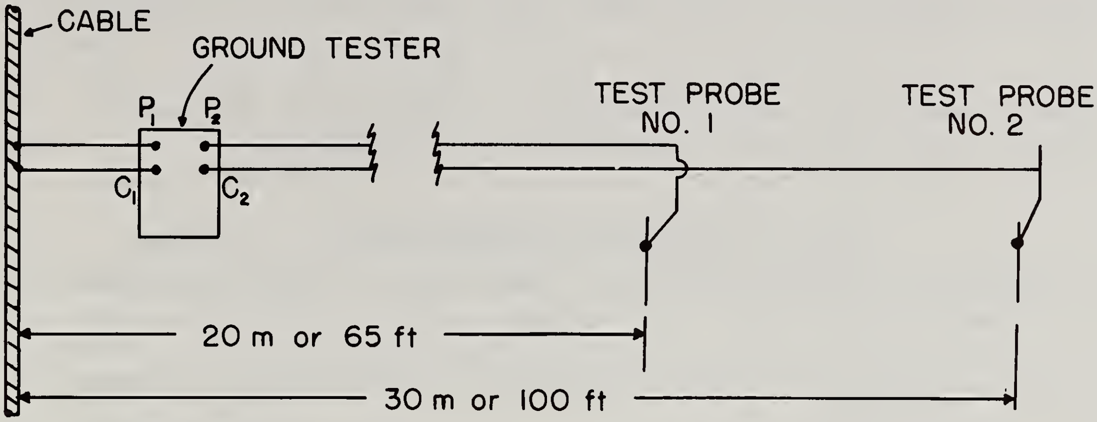


Fig. 14. Connections and placement of test probes for measuring neutral-to-earth resistance.

The resistance-to-earth of the system neutral is likely to be less than one ohm where grounding conditions are favorable or several ohms where earth resistivities are high. An unusually high resistance or a sudden change compared with the next measurement along the cable may indicate that neutral wires have been severed due to corrosion. Low resistance-to-earth of the neutral does not necessarily prove that the neutral is continuous but it does give assurance of effective grounding at the location where measured.

In interpreting the data, watch for variations as well as the values of potential and neutral resistance-to-earth. In areas where corrosion is not serious, neutral resistance-to-earth should not change much from point to point along the line and changes in potential will be less than in areas where corrosion is more serious. An abrupt change in dc potential and/or neutral-to-earth resistance within a short distance may indicate a discontinuity of the neutral or a substantial flow of direct current along the neutral. If there is a major change in soil resistivity, the probability of corrosion (in the lower-resistivity soil, usually) is increased.

Care is needed to have a solid connection to all neutral wires of the cable. Resistance of this connection is seen by the instrument as part of the resistance-to-earth. If a four-terminal instrument is being used, one pair of terminals marked C and P is used for the common connection to the neutral while the other C and P terminals are connected to test probes 2 and 1, respectively. For the cable connection, separate connecting leads as shown in Fig. 14 should give the most accurate results.

A practice of posting observations on a detail map sheet has been found to be very helpful in interpreting the readings. Separate symbols or different colors should be used in recording potential, neutral resistivity-to-earth, and earth resistivities at the locations of the observations.

EARTH RESISTIVITY

Earth resistivity measurements have at least three purposes in corrosion surveys:

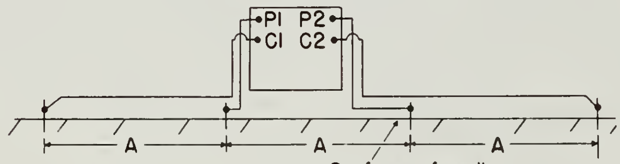
1. To select the lowest-resistivity locations for sacrificial anodes. Unless the anodes are carefully located to take advantage of low-resistivity locations, results are likely to be unsatisfactory.

2. To decide on sizes and types of anodes to install at each location for effectiveness and long useful life. (For details about selection of anodes, see Part IV.)

3. To identify major changes in soil characteristics that may correspond to locations of corrosion.

Earth resistivity is measured by use of a four-terminal ground tester using four test pins or probes equally spaced along a straight line as shown in Fig. 15. Earth resistivity may be expressed in ohms per centimeter cube (ohm-cm) meaning the resistance between opposite faces of a cube measuring 1 centimeter along each edge.

The four test pins should be located away from buried metal that might provide a conducting path between them. For measurements along an underground bare-neutral cable, keep away from the cable at least the distance A between test pins and more if possible. It is preferable, when feasible, to place the pins in a line perpendicular to the cable rather than parallel to it.



Spacing A	Multiply by	Examples:
1.6 m (5.2 ft)	1000	for 1.6 m spacing:
3.2 m (10.4 ft)	2000	If meter reads R = 2.4 ohms

Resistivity = 2.4 x 1000
= 2400 ohm-cm

Fig. 15. Measurement of earth resistivity with a four-terminal ground tester.

The ground tester operates by injecting a square wave current between the outer C1 and C2 terminals and sensing voltage drop between P1 and P2. The meter indication is in ohms. To obtain the value of resistivity in ohm-cm, the meter indication R is multiplied by a factor depending on the spacing A between test pins as shown in Fig. 15. This resistivity is the average to a depth equal to A, of the volume of earth located between the two center pins.

RECORDING AND INTERPRETING DATA

Accurate recording of field data can be made easier by use of a data sheet such as shown in Fig. 16 for general corrosion surveys and Fig. 13 for potential and earth resistivity profiles. These data sheets are provided as samples, which should be changed as necessary to satisfy the needs in particular surveys.

For interpretation and for designing cathodic protection, it is often helpful to have the observations recorded on a detail map so that variations along the route and differences between observations can be more easily seen.

Fig. 16.
Sample Field Survey Data Sheet

Cooperative:			Date:					By:			Page No:		
Map Location	Station (distance)	Half-cell Potential	Earth Resistivity			N-Gnd Res.*	Guy Current			Pole Line Neutral			
			Spacing	R	ρ		Size	V Drop	I	Size	Type	Span	I
	_m _ft	volt	_m_ft	ohms	ohm-cm	ohms	_mm_in	μV	ma	AWG		ft	ma

*Measure directly from cable neutral

MANUAL ON UNDERGROUND CORROSION CONTROL IN RURAL ELECTRIC SYSTEMS

PART IV. CORRECTIVE AND PREVENTIVE MEASURES

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MANUAL ON UNDERGROUND CORROSION CONTROL IN RURAL ELECTRIC SYSTEMS

PART IV. CORRECTIVE AND PREVENTIVE MEASURES

GENERAL

In planning steps to take against underground corrosion, it is often difficult to decide where to start. The usual situation is that there is too little time and too much to do. How do we decide priorities?

In work scheduling, the requirements for repairing damage, corrosion control and prevention of future difficulties must find their place along with other repairs and improvements. The following categories might be used for that purpose.

1. Immediate repairs, requiring attention such as would be given to a "danger pole," a low-hanging conductor, or loss of grounding on a pole line. These are conditions presenting immediate hazards to life and property such that a crew should be dispatched promptly to make necessary repairs.

2. Priority repairs, where unacceptable, costly damage or interruptions to service might otherwise occur. Such work would have priority but, compared with emergencies, could be scheduled with more regard to costs and other work.

3. Routine maintenance and improvements which, like routine pole or conductor replacement, can be scheduled on an area basis for the best results at least cost and disruption of other work.

4. Corrosion prevention through changes in designs, specifications and materials for new construction so that foreseeable future problems will be avoided.

REPAIRS ON EXISTING FACILITIES

Immediate Repairs

Even immediate or emergency repairs should be made in a way which, insofar as possible, will be consistent with overall plans for corrosion control. The materials used for repairs should usually be the same as those for future construction.

Restoration of grounding. Loss of effective grounding due to underground corrosion has been observed only on rare occasions. Any indication of inadequate grounding calls for immediate corrective measures, to assure proper operation of protective apparatus under lightning or fault conditions and to assure safety of workers and the public.

Stray current dc interference discussed in Part V of this manual, can cause rapid destruction of ground connections as well as other buried metal. If this occurs, immediate steps should be taken to install additional grounds and also to eliminate the source of the interference.

Loss of effective grounding along an underground distribution cable may indicate deterioration of the bare copper concentric neutral wires and corrosion of the galvanized steel ground rods. The quickest means for improvement, with least cost and disturbance of consumer property, is by installation of additional ground rods at the transformer or other structure where better grounding is needed. Next would be replacement of cable or installation of a neutral conductor to adjacent locations of grounds at other equipment. The following steps are suggested:

1. At the distribution transformers or other apparatus, drive and connect additional galvanized steel ground rods to restore a satisfactory resistance-to-earth and eliminate objectionable ac voltages.

2. If necessary, drive additional ground rods at adjacent locations to which the neutral wires are continuous.

3. In the absence of adequate neutral conductivity, install new cables or a new neutral conductor to the adjacent locations and install additional ground rods as necessary.

4. Install sacrificial anodes as necessary for cathodic protection of neutral wires and ground rods.

Galvanized mild steel ground rods are suggested rather than copper-jacketed or stainless steel rods, for several reasons:

1. To maintain overall integrity of the neutral and grounds by minimizing the possibility of further underground corrosion of copper neutral wires and ground wires. Experience has shown that copper is usually protected against corrosion when connected to underground steel or iron.

2. To minimize vulnerability to ac corrosion. Mild steel is more resistant to ac corrosion than copper and may be preferable in that respect to stainless steel.

3. To minimize the cost and the difficulty of achieving additional cathodic protection by means of magnesium or zinc anodes.

An adequate inspection and maintenance program, and installation of cathodic protection as necessary, are important parts of the corrective action. Keep in mind that steel rods, to satisfy code requirements as grounds, are required by the National Electrical Safety Code (Par. 94B.1) to be "of metals or combinations of metals which do not corrode excessively under the existing conditions for the expected service life."

Replacement of Failed Anchors

When a corroded anchor rod and anchor are replaced, the corrosion should be recognized as a symptom of a probable larger problem in need of attention. Additional steps may be called for to avoid excessive corrosion of the new anchor rod and other underground metal. The following are suggested:

1. As a minimum, if the corrosion was excessive (for example, failure in less than 20 or 30 years), install a sacrificial anode of suitable size and type at the time of anchor replacement. For anode size and type, see Table I, page 8.

2. Avoid any general use of guy strain insulators for preventing anchor rod corrosion. The strain insulator usually does not correct the problem but shifts it elsewhere. (Note, however, that strain insulators may be needed at some cable terminal poles and in some stray current situations as described in Part V.)

An illustration of anchor rod corrosion as part of a larger problem is shown in Fig. 1. The arrows represent direct currents flowing from an underground cable onto the pole line neutral. Corrosion is occurring where the currents return to earth at the guy anchor and elsewhere along the pole line. To correct the larger problem, sacrificial anodes should be installed as shown in Figs. 2 and 3. Strain insulators may be called for at a terminal pole that is not near a satisfactory anode location, but if so, anodes are needed elsewhere to compensate for effects of the cable.

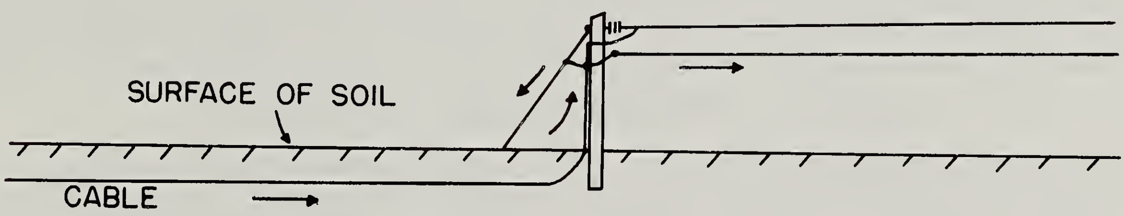

Fig. 1. Direct currents (movement of positive charges) along the electric neutral and guy at a cable terminal pole.

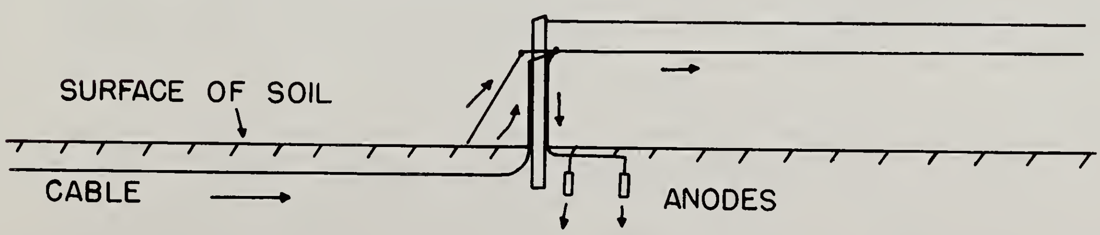

Fig. 2. Direct currents near a cable terminal pole with sacrificial anodes.

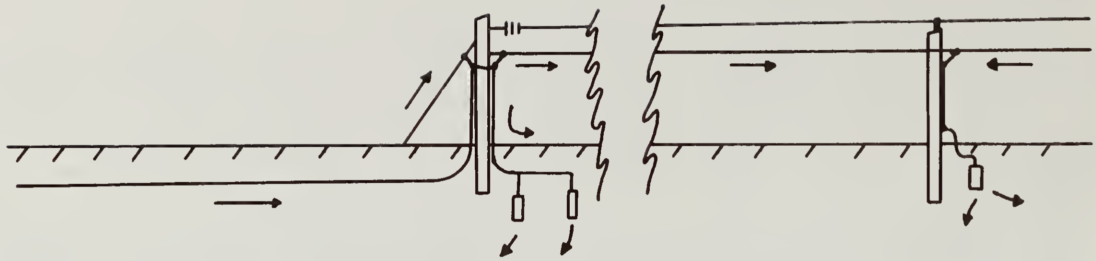

Fig. 3. Direct currents near a cable terminal pole with sacrificial anodes protecting riser pole guys and grounds along overhead lines.

In most situations, strain insulators tend to shift damage to other locations. Therefore, a sacrificial anode at the offending location is much more helpful than a strain insulator, as part of an overall solution to the corrosion problem.

Priority Repairs for Preventing Damage

In addition to immediate repairs, some corrective actions taken soon enough may prevent major damage or probable service interruptions at a relatively small cost. Chief among these are the protection of concentric cable neutral wires subject to deterioration and the replacement of corroding anchor assemblies.

Concentric cable neutral wires. Cable neutral wires have sometimes been subject to rapid corrosion such that at times the wires are severed within a year or two after installation. This has occurred on buried cables not yet connected or energized as well as on cables in service. To minimize such possible damage, some cathodic protection may be desired with a minimum of delay. The following are suggested:

1. In existing subdivisions or other high load density locations, install additional steel ground rods at all loads. Install anodes as needed to extend the life of the ground rods and the cable.

2. In less congested areas, if anodes are needed, install some anodes at low-earth-resistivity locations even if complete protection is not feasible at this time. Locations may be available near pad-mounted equipment or at terminal poles where connections can be made above ground, or at low resistivity locations where groups of anodes would have maximum "throwing power."

Pole line anchors and anchor rods. If anchor rods have failed due to corrosion, other locations of probable failures can usually be found quickly through use of guy currents surveys (assuming that guys are bonded to the neutral). Replacement of anchors and/or installation of anodes where guy currents are greatest can yield big dividends in terms of freedom from trouble and protection against further corrosion,

at a relatively low cost. At any location of significant anchor rod corrosion, a sacrificial anode protecting the anchor provides a zone of protection nearby, often to a distance up to 500 meters along a pole line. It is for this reason that additional benefits are available at relatively small cost by installing sacrificial anodes at the time that anchors are replaced. This is particularly true if there are no immediate plans for future testing and corrosion surveys. Corrosion of the anchor rod indicates that a sacrificial anode at that location should be effective.

Completing Repairs of Corroded Underground Cables

When underground cable neutral wires are found to be corroded, the first action normally called for is to install adequate grounding and anodes where needed to assure safe operation and electrical protection. These steps have been described under Immediate Repairs.

Additional repairs or replacement may be necessary to assure satisfactory reliability and service life of the cable. The specific actions may be replacement of lengths of cable, connecting a new neutral conductor across each damaged section of cable, or abandoning and replacing with other facilities. Or, if neutrals are corroded but still intact, cathodic protection should be considered to minimize future deterioration of neutral wires.

It must be assumed that there are increased risks of cable insulation failure and increased dig-in hazards if the concentric neutral wires are corroded or gone. The importance of these considerations must be weighed in light of accessibility of the cables, future development plans along the cable route and long-term importance of this particular circuit.

CATHODIC PROTECTION WITH SACRIFICIAL ANODES

Cathodic protection of buried metal is accomplished by causing the metal to be cathodic; that is, by causing a direct current (positive ions) to flow into the metal from the surrounding soil. This can be accomplished by use of sacrificial (galvanic) anodes or by impressing dc voltages and currents by means of a rectifier served from an ac source.

Anodes used in soil are of zinc or magnesium, installed in special packages of prepared backfill to improve performance. Metal purity and the alloying of these anodes are carefully controlled. Commercial zinc or magnesium manufactured for other purposes is likely to give poor results and therefore should not be used for galvanic anodes. Results may also be poor in absence of proper backfill, which should completely surround the anode so it is not in direct contact with the soil.

Electrical relationships showing how anodes work are indicated in Figs. 4 and 5.

Fig. 4 shows dc potentials of a magnesium anode, a zinc anode and a pole line neutral conductor. The potentials are specified with reference to a copper-copper sulfate half cell and can be observed by use of the dc voltmeter. The potentials -1.55 volt and -1.1 volt are typical of the open-circuit potentials to a copper-copper sulfate half cell of magnesium and zinc anodes. The -0.4 potential of the electric nuetral represents the combined effect of all underground material connected to the neutral and will vary considerably with grounding practices and soil type.

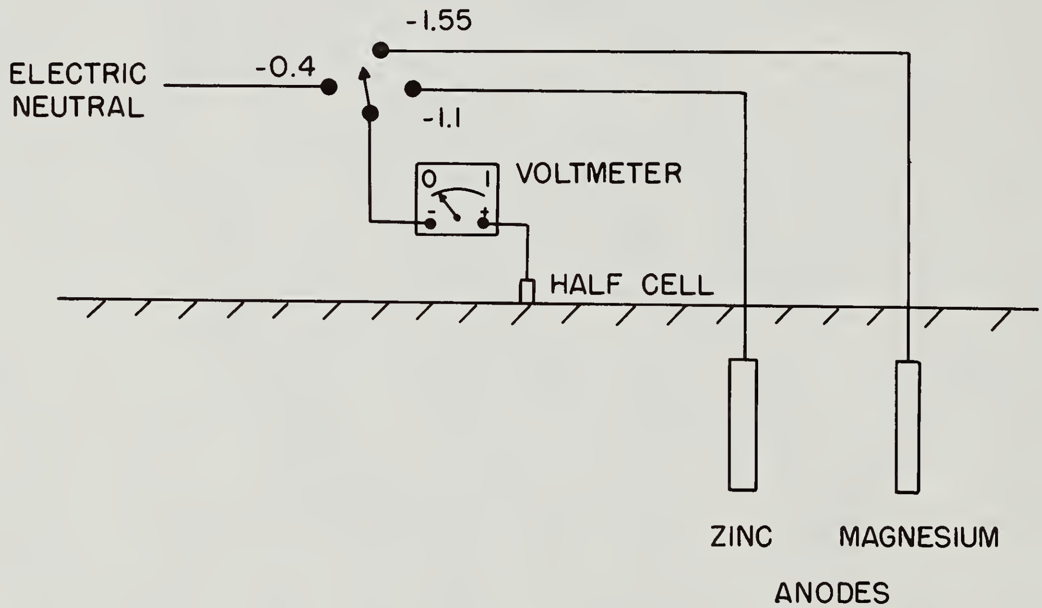

Fig. 4. Potentials of an electric neutral conductor and of magnesium and zinc anodes.

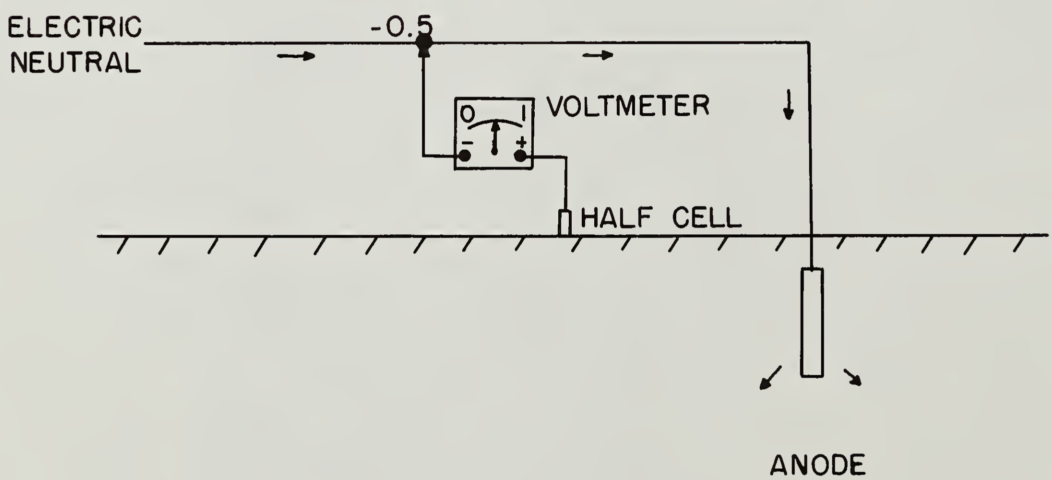

Fig. 5. Potential and direction of dc (movement of positive charge) with an anode connected to the neutral conductor.

The neutral potential becomes more negative if an anode is connected, and direct currents (movement of positive charge) flow as shown in Fig. 5. The resulting potential is shown as -0.5 volt, but it could have any value between the "as found" potential (-0.4 volt) and the open-circuit potential of the anode. The dc potential change (or potential shift) of the neutral, due to the anode, indicates effectiveness of the anode.

The amount of current discharged by the anode and its effectiveness are dependent on resistance-to-earth of the anode which in turn depends on earth resistivity at that location. Also, the amount of current depends on driving voltage, which is the difference between the open circuit potential (-1.55 volts for magnesium and -1.1 volts for zinc) and the potential of the protected structure, -0.5 volt in this example.

The anode is gradually consumed at a rate proportional to the current discharged. Reasonable assumptions for purposes of design are one kilogram per 1100 ampere hours (1 lb. per 500 Ahrs) for magnesium and one kg per 740 Ahrs (1 lb. per 335 Ahrs) for zinc, for properly alloyed anodes in prepared backfill.

Cathodic Protection of Pole Line Anchors

Anchor rod corrosion problems along rural pole lines (excluding those due to stray currents) have generally occurred only when grounding was with copper and where soils were quite corrosive. Even in these situations, good results have been achieved by a procedure as follows:

1. Identify locations of relatively severe corrosion, by measuring dc corrosion currents in guys.

2. Replace anchor assemblies, beginning at locations where guy currents and time in service would indicate the severest corrosion. From the degree of damage found on anchor rods and the guy currents observed, decide where to replace anchors at other locations.

3. Install anodes at locations where anchor rods have corroded and where guy currents exceed a specified value such as 10 mA.

4. Consider standardizing on steel grounding materials for new construction and for replacements, to further increase the amount of buried steel compared with copper.

Where anchor rod corrosion is not considered serious enough to justify a survey of currents in guys, the following procedure is suggested:

1. Wherever an anchor rod is replaced because of early failure or serious damage due to corrosion (for example, within 15 years or less), install a sacrificial anode at the time the new anchor is installed.

2. Use galvanized steel grounding materials in all new construction to further reduce the probability of corrosion problems in the future.

The anode type and size for protecting an anchor rod may be selected on the basis of either earth resistivity, guy current or age of the corroded anchor assembly in accordance with Table I.

TABLE I

Suggested Anode Sizes for Protecting Anchor Rods Connected to a Copper-Grounded·Pole Line Neutral.*

Earth Resistivity	Anchor Rod Experience		Packaged Anode Size and Type
	Time Before Corrosion Failure	Guy Current	
(ohm-cm)	(years)	(mA)	
500	5 or less	25 or more	27 kg (60 lb) zinc
1000 to 2500	6 to 10	10 to 25	14 kg (30 lb) zinc
3000 to 5000	10 to 20	5 to 10	7.7 kg (17 lb) magnesium

*If located a mile or less from underground cable, see additional discussions which follow.

The suggestions in Table I should give satisfactory results in most situations. For more accurate design, Figs. 6 and 7 and the design procedures as suggested for underground cables may be used.

Potentials for Cathodic Protection of Bare-Neutral Underground Cable

To understand the meaning of negative dc potentials to control corrosion, it will be helpful to recall the relationships illustrated in Figs. 1, 2 and 3 of Part II, Introduction to Corrosion.

As mentioned in Part II, a piece of metal with a uniform surface in uniform soil reaches an equilibrium at a dc potential such that little corrosion occurs. If such a piece of metal were made only slightly more negative, the entire surface would become cathodic and thus protected against corrosion.

In a variable soil environment, there is a variation in the equilibrium potentials of metal surfaces at various locations. A larger metal structure, such as a continuous steel pipe or a long copper wire, thus becomes more vulnerable to corrosion. To protect this larger structure requires the application of a more negative dc potential.

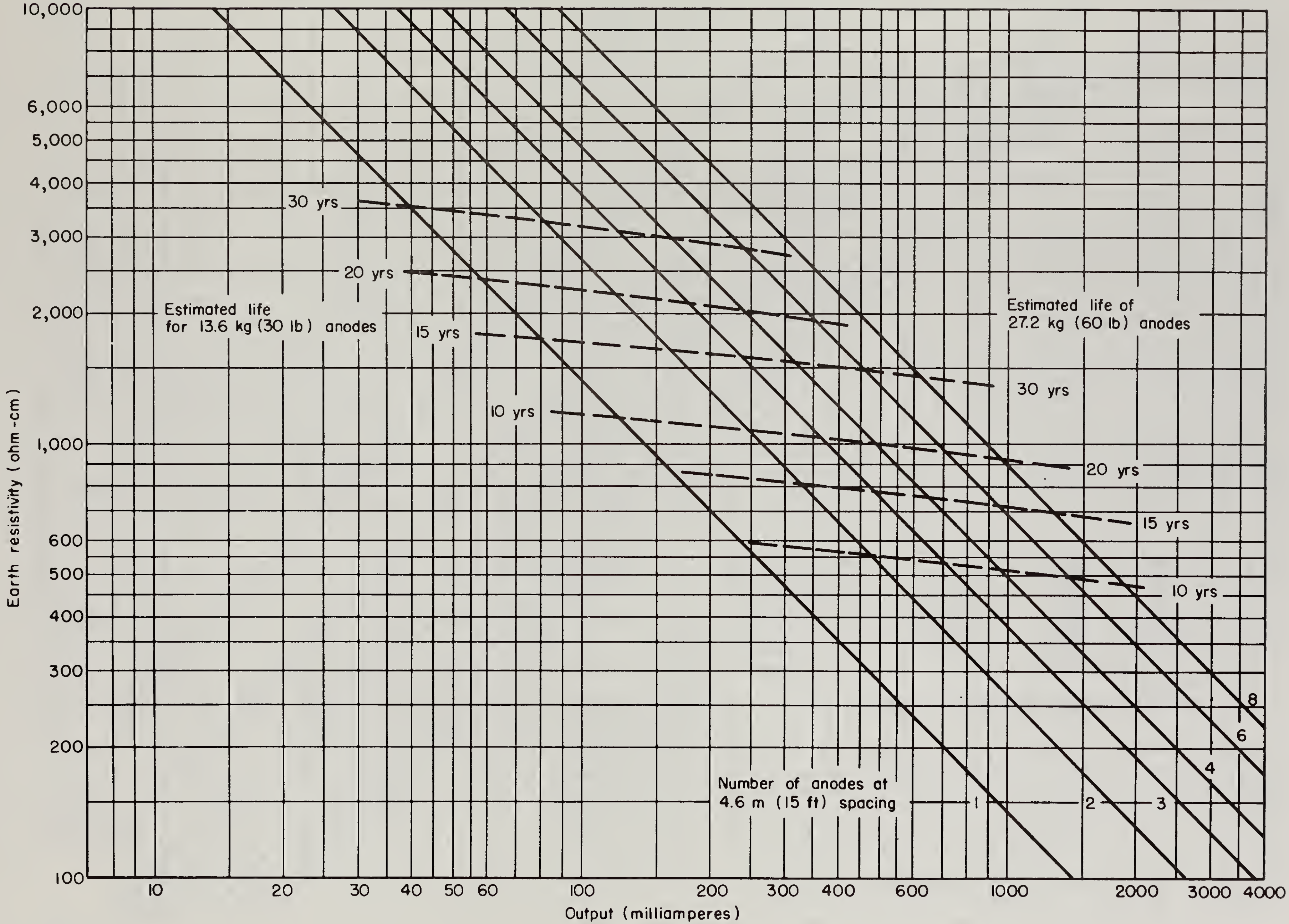

Fig. 6. Current output and estimated life of zinc anodes

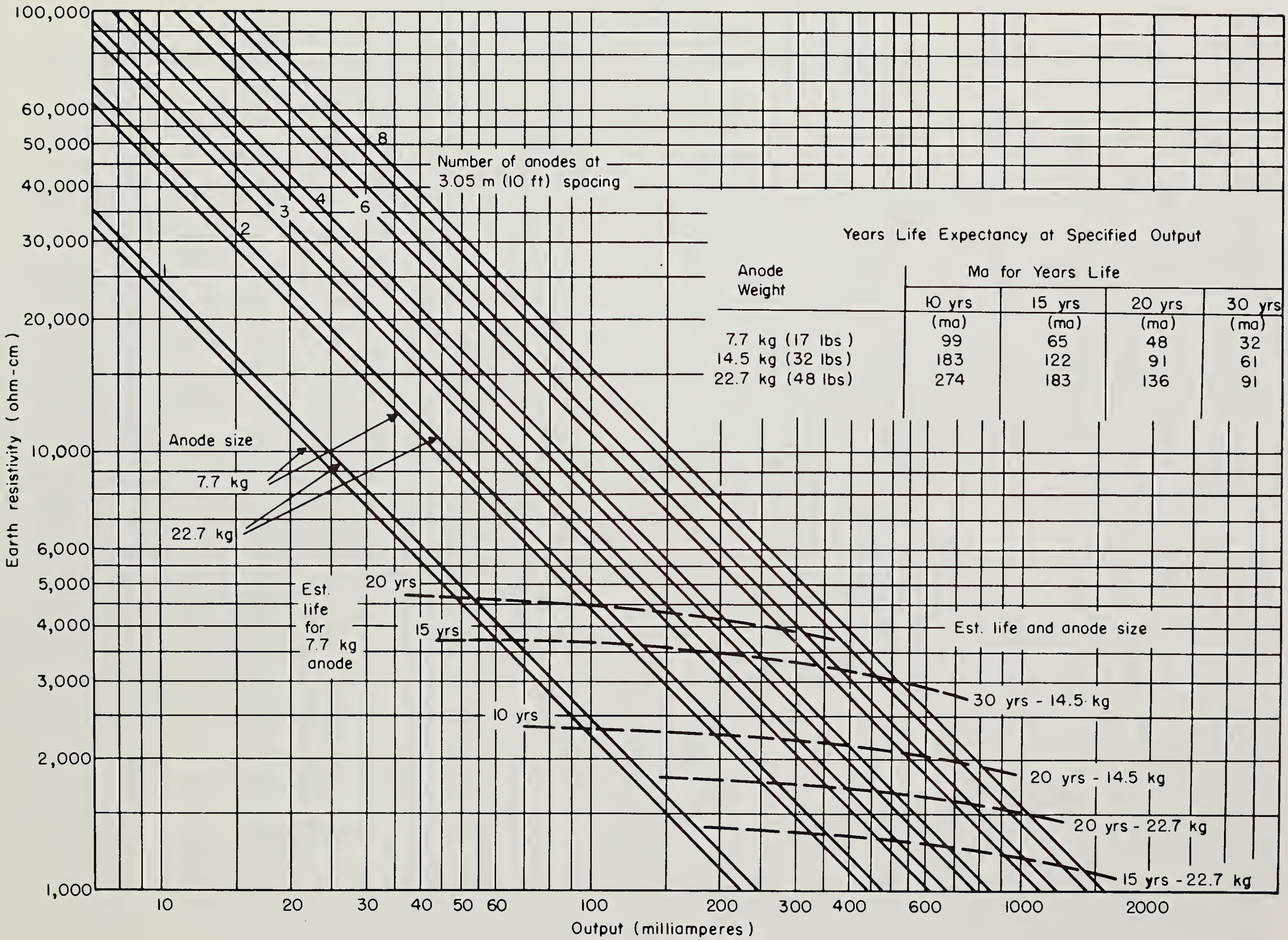

Fig. 7. Current output and estimated life of magnesium anodes

Protection of buried iron and steel. For buried iron or steel, experience has shown that a potential of -0.85 volt or more negative to a copper-copper sulfate half cell generally provides protection even in the most corrosive soils. In less corrosive soils, less negative potentials such as -0.7 or -0.5 volt might provide effective protection. A long steel pipe that is not cathodically protected and passes through various soils can be expected to have some intermediate half-cell potential, such as -0.6 volt.

The accepted rule for cathodic protection of underground iron and steel, for the pipeline industry and others, is to satisfy one or both of the following criteria:[1]

1. A potential of -0.85 volt or more negative to a copper-copper sulfate half cell.

2. A potential shift of -300 mV (-0.3 volt) due to application of cathodic protection.

Protection of buried copper. The data on cathodic protection of buried copper are quite limited, but experience gives some significant indications of potentials at which corrosion does or does not occur.

Many years of favorable experience, prior to wide use of underground construction, indicate an absence of underground copper corrosion on overhead electric systems. Reasons for this favorable experience may be found by measuring dc half-cell potentials of neutrals and grounds along these older lines. In REA experience, copper grounded overhead distribution lines and distribution substations have usually had potentials of -0.45 to -0.6 volt to a copper-copper sulfate half cell. These potentials, relatively negative for copper, result from the presence of guy anchors and other buried steel connected to the neutral. Steel-grounded neutrals were more negative by 0.1 to 0.15 volts, based on a few measurements in South Dakota. In all of these instances, potentials are such that copper is not likely to corrode.

Bare neutral wires of underground cables are at less negative potentials than pole line neutrals, often approaching -0.1 volt or zero to a half cell. Earlier studies indicate that copper corrosion is possible at -0.10 volt or less negative and probable at zero or positive half-cell potentials.[2] Additional experience now indicates that copper may corrode at more negative half-cell potentials as great as -0.4 to -0.5 volt.[4]

What, then, should be the criteria for cathodic protection of copper? In a large majority of soils, a potential of -0.35 volt or more negative to a copper-copper sulfate half cell evidently protects buried copper against corrosion. However, experience in a few instances indicates the need for half-cell potentials more negative than -0.5 volt.

Protection of interconnected copper and steel. Requirements become more difficult to define when cathodic protection is applied to underground copper and steel, where both metals are connected to the system neutral.

Where past experience has been favorable, half-cell potentials on older parts of the system will indicate the levels at which both copper and steel have been adequately protected, or, at least, have not experienced severe corrosion. The pattern of potentials in these and other sections of the system, along with other observed experience, is the best source of information for deciding on the potentials desired for cathodic protection.

In the absence of other data, a half-cell potential of -0.5 volt is suggested for design of cathodic protection for the electric neutral and grounds until further experience is gained. The illustrations that follow assume a "protected" neutral potential of -0.5 volt. For other levels, the data can be adjusted as will be described.

Current Requirements for Cathodic Protection of Underground Cable

A sacrificial anode serves its purpose by drawing dc current from the neutral and discharging it into the earth. This anode current returns to the neutral at other locations to provide cathodic protection. The big question is, how large must the current be to give the results desired? For anchor rod and "hot spot" protection along pole lines, this question can be largely disregarded. Current requirements do become important where the cost of cathodic protection is likely to be substantial, as in protecting underground cable.

The currents required for cathodic protection vary so widely according to soil properties that any advance estimates may be far off the mark. Therefore, a degree of "trial and error" is often necessary in design. Cathodic protection is applied, potentials are monitored and then changes are made in light of experience. However, as experience is gained on one's own or a nearby system, estimates should become more reliable and results more predictable.

The initial design of cathodic protection may be based either on estimated current requirements or on an assumed number of sacrificial anodes required for each mile of cable.

Estimating current requirements. Current requirements for cathodic protection are usually expressed in mA/m^2 or mA/sq ft of protected surface area. The usual practice for bare-neutral underground cable is to include only the surfaces of the concentric neutral wires. No. 14 AWG (1.63 millimeters or 0.064 inches in diameter) wire has a surface area of approximately one square meter for each 195 meters length or one square foot for each 59.5 linear feet. For No. 12 AWG (2.05 mm or 0.0808 in) wire, the surface areas are $1m^2$ per 155 m or 1 ft^2 per 47 ft. These figures should be adjusted to allow for the spiraling or lay of the neutral wires on underground cable. If 10 percent is allowed for lay of the wires, surface areas per meter or foot length are as follows:

Wire(s) Number and AWG Size	Length per Unit of Surface Area For each square meter	For each square foot
	(m)	(ft)
1 No. 14	175	54
1 No. 12	140	42
6 No. 14	30	9.0
10 No. 14	18	5.4
27 No. 14	6.5	2.0

Using the figures above, current densities in terms of mA/m^2 or mA/ft^2 can be translated into mA per meter or per foot of cable route. To provide numerical values for an example, a current density, of 3.2 mA per m^2 (0.3 mA per ft^2) of neutral wires surface area, on a three-phase cable with 27 No. 14 AWG neutral wires would be equivalent to approximately 0.50 mA per meter of 0.15 mA per foot of cable route.

Estimating the number of anodes needed. In order to learn how many anodes will be needed, we need to know the estimated current requirements for cathodic protection. It is also necessary to measure earth resistivities at the proposed anode locations. With this information, refer to the appropriate current output charts, Figs. 6 and 7, for the sizes and types of anodes to be used.

Estimating Numbers of Anodes Without Current Data

A "first trial" design might be made simply by deciding to install a specified number of anodes for each km or mile of cable route. For example, four anodes per cable mile has been suggested for cables with approximately 10 No. 14 AWG bare tinned neutral wires. This would mean a total of 12 sacrificial anodes for each mile of three-phase cable route or four for each mile of single phase.

Selecting Anode Locations

Anodes, to be effective, must be at the locations of low earth resistivity, preferably the lowest resistivity locations available. This is so important that earth resistivity measurements should always be required at locations being considered for anodes. The only exceptions are at locations such as mentioned for anchor rod corrosion, where corrosion experience has proven that the site is a good one for an anode. Resistivity measurements show where each anode will perform best. They also are used to calculate the approximate rate at which the anode will be expended and, therefore, the type and size needed.

Earth resistivity should be measured at intervals not greater than 0.16 km (0.1 mile), initially. The interval should be shortened to half that distance where resistivities vary over a range of more than 3 to 1 (for example 6000 to 2000 ohm-cm). As experience is gained, less measurements may be needed. Additional measurements are desirable at locations of low resistivity to identify locations for anodes.

The number of anode sites needed along a cable route will vary, with longer intervals where the soil resistivity varies widely and shorter intervals where the soil resistivity is uniform. Experience suggests that at least one anode location in each quarter mile is desirable. The requirements vary with soil and terrain. Wider spacing may be acceptable if dc potentials at risers or services should be relatively negative to protect buried steel but less negative potentials are needed at remote locations to protect copper neutral wires midway between services.

Selecting Anodes

Sacrificial anodes for use in soil are made of high-purity magnesium or zinc which may be alloyed with small amounts of other metals to assure good performance as sacrificial anodes. The anodes are packaged in prepared backfill of gypsum and bentonite clay to further improve reliability of dc output. Anodes of metal that do not meet the appropriate specifications or any anodes in direct contact with native soil may perform poorly or become completely ineffective within a few years.

Packaged magnesium and zinc anodes with connecting leads have appearances and dimensions approximately as shown in Fig. 8 and Table II.

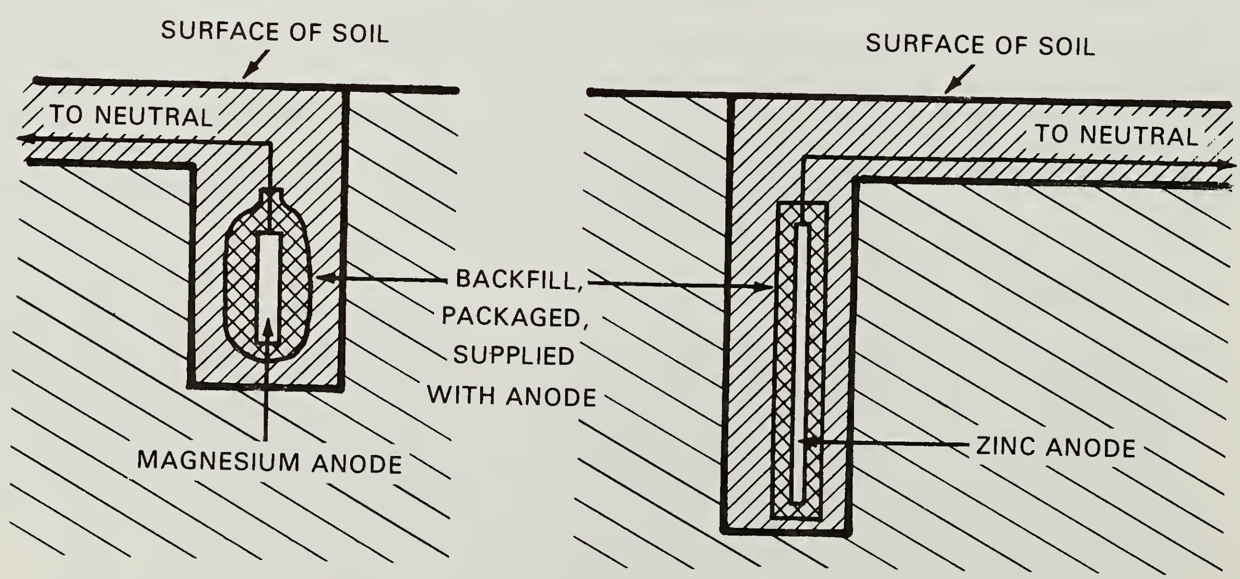

Fig. 8. Typical magnesium and zinc anodes, installed.

TABLE II

Common Types and Sizes of Sacrificial Anodes

Anode Weight		Industry Type	Packaged Anode				Approximate Capacity
			Diameter		Length		
kg	(lb)		cm	(in)	cm	(in)	Ampere years
Zinc							
13.6	(30)	ZI-2-30	15	(6)	170	(66)	1.1
27.2	(60)	ZI-4-60	15	(6)	170	(66)	2.3
Magnesium							
7.7	(17)		17	(6½)	74	(29)	1.
14.5	(32)		20	(8)	71	(28)	2.
22.7	(50)		25.4	(10)	61	(24)	2.7

Magnesium anodes generally have higher driving voltage, higher output current and shorter life than zinc anodes of equivalent size installed under the same conditions. Therefore, magnesium has advantages in soils with higher resistivities such as 3000 ohm-cm or higher, while zinc has advantages in low resistivity soils and where long anode life is desired. In many instances, either zinc or magnesium can be used and the choice is influenced by the cost for equivalent results with each type of anode.

Fig. 6 shows the estimated current output and life of packaged zinc anodes in soils with resistivities of 100 to 10,000 ohm-cm, for installations of 1 to 8 anodes. The two most used sizes of zinc anodes have similar output characteristics so a single set of curves is used. Anode spacing at closer intervals than indicated in Fig. 6 would cause some reduction in output. The differences should not be very significant for separations down to 3 m (10 ft).

Fig. 7 shows the estimated output and life of three standard sizes of packaged magnesium anodes in soils with resistivities of 1,000 to 100,000 ohm-cm. Outputs differ according to size; so separate curves are shown for the largest and smallest sizes. The 14.5 kg anodes would fall approximately midway between the two curves shown.

MATERIALS AND DESIGNS FOR NEW CONSTRUCTION

Many corrosion problems can be avoided at little additional cost at the time of original construction, if optimum choices are made of materials and designs. To do this, however, may require changes in materials and designs that have been used without question for many years. Some assumptions which were relied upon in the past are not entirely true when examined in the light of new evidence.

New Evidence Concerning Corrosion

Some of the most important new evidence and conclusions are as follows:

1. Copper, buried by itself, can corrode in soil. Tinned copper cable neutral wires have sometimes been found to corrode at half-cell potentials less negative than -0.15 volt, with the probability of corrosion increasing as potentials become less negative or more positive. A few recent observations have indicated copper corrosion in certain soils even when potentials are -0.4 to -0.5 volt to a copper-copper sulfate half cell.

   The rates of copper corrosion in a variety of soils have been determined in burial tests in which short pipe specimens were buried during the 1930's. The results, published by the National Bureau of Standards, indicated pit depths after 14.3 years of 16.3 mm (65 mils) in cinders, 4 to 12 mm (16 to 48 mils) in muck, peat and one type of clay, and negligible pit depths in other soils.[3] Long pipes or wires extending through different soils can be expected to corrode more rapidly than short test specimens such as the 30.5 cm (12 in.) pipe specimens used in the NBS tests.

2. Steel and iron in soil generally have a long useful life, partly because the thickness of material is usually enough to tolerate some corrosion. The exceptions, where corrosion may be excessive, are usually foreseeable. Unacceptable rates of corrosion can generally be avoided through proper design and the use of corrosion control measures.

3. Dissimilar metals have frequently been buried and connected together with no evident difficulty due to corrosion. This seems due to polarization films such as were discussed in Part II of this manual. In any event, properly designed grounding systems including copper and substantial amounts of steel usually have not resulted in any obvious difficulties due to corrosion.

How can one rely on such conclusions when experience is lacking? The answer is to observe and interpret the experience at hand in one's own or a similar service area. Examples are:

1. Regarding corrosion of iron by itself (not connected to larger amounts of copper), what are thicknesses of the metal and useful life of highway culverts, steel well casings (usually much larger than nearby copper grounds that may be connected), iron or steel pipes not connected to an electric ground, driven pipe grounds for lightning protection of buildings, and steel pipes (not galvanized) for farm fences or (galvanized) for industrial fences?

2. Regarding grounding systems with copper and steel interconnected:

a. What is the past experience with anchors bonded to a copper grounded neutral when no underground cable was present? For example:

   o Some anchors in low spots may have failed or were considerably corroded after 20-30 years; or

   o Occasional failures may occur after 15-20 years of service; or

   o Some failures may have occurred within 5 to 10 years after installation.

   In these grounding systems, what are estimates of the surface areas of buried copper and buried steel in a typical one-half mile? Is experience available from comparable areas where the proportions were different?

b. What has been the experience with anchor rods (with bonded guys) adjacent to copper-grounded substations? What are the estimated surface areas of buried copper and steel? What is the half-cell potential of such a substation serving pole line distribution (no underground cable within a mile)?

c. What are the neutral half-cell potentials of older pole line facilities, where experience has indicated no underground corrosion (or known amounts of underground corrosion) of either steel or copper?

Designing to Avoid Corrosion Problems

Much of the present knowledge and experience concerning corrosion can be condensed into a few ground rules which point the way to go so that high costs of underground corrosion will be largely avoided.

1. Avoid use of dissimilar metal (or burial in dissimilar soils) such that critical components are likely to become severed or destroyed during the life of the installation. If such might occur, include cathodic protection at the time of original construction.

2. Where dissimilar metals (buried copper and steel) will be present, make maximum use of galvanized steel and avoid additional underground copper except where necessary for conductivity. Consider plating or insulation of buried copper wires to further minimize effects of the copper, in low resistivity (corrosive) soils.

3. Install additional cathodic protection where needed to prevent excessive corrosion. (The galvanizing on buried steel provides cathodic protection which may or may not be sufficient.)

4. In soils known to be corrosive, do one or more of the following:

   a. Use coatings or insulated copper where appropriate.

   b. Use greater amounts of cathodic protection.

c. Use steel or iron of larger cross section, where these materials are used underground.

Distribution System Grounding

Galvanized steel materials are suggested for grounding of all distribution lines, above-ground and underground. This is a continuation of practices that have been recommended by REA since the early 1960's for pole lines and, more recently, for underground construction. The chief reasons for this are:

1. Buried steel connected to neutrals and grounds is usually present at many locations along an electric distribution line. If some buried steel is insulated from the neutral or copper used instead, other steel still connected or overlooked is corroded more rapidly. To eliminate all steel connected to the neutral and grounds is usually not feasible.

2. REA experience with pole lines has shown that corrosion of buried steel, including guy anchors connected to the neutral, presents no significant problems in most soils. Where excessive numbers of anchor rod failures were experienced along overhead lines, the situation was corrected at relatively low cost by standardizing on use of galvanized steel grounding materials, supplemented in a few instances with sacrificial zinc or magnesium anodes.

3. Underground construction increases the probability of excessive underground corrosion; so cathodic protection often becomes necessary with the presence of buried bare-neutral cable and also with semicon-jacketed cable.

   a. A higher level of cathodic protection (a more negative potential) is needed with steel grounding than with copper to avoid excessive corrosion of the steel ground rods. However, the cathodic protection also becomes less costly and easier to achieve when more buried steel and less copper is present in the grounding system.

   b. Galvanized steel ground rods, together with higher levels of protection (where cathodic protection is needed), bring two important benefits:

      (1) The possibility of excessive corrosion of buried steel in other facilities connected to the underground cable is largely eliminated.

      (2) Underground corrosion of copper is not likely to occur even at remote locations, since the dc potentials needed to protect copper are less negative than those for protecting steel or iron.

Direct-Buried Cables

Suggestions for new underground construction are as follows:

1. Continue use of 3/4-inch galvanized steel ground rods for all underground as well as overhead distribution construction.

2. Consider the installation of cathodic protection on future installations of bare-neutral underground cable, to accomplish the following:

    a. To avoid corrosion of copper neutral and ground wires.

    b. To avoid adverse effects of the cable on adjacent facilities including pole lines and buried interconnected metallic structures owned by others.

    c. To avoid excessive corrosion of steel guy anchors and ground rods.

3. Avoid installation of bare-neutral cable in conduit, particularly nonmetallic conduit. The inside of a conduit may become a corrosive environment because of variations such as soil, mud, water and air inside the conduit. Also, nonmetallic conduit prevents cathodic protection from exterior sources from reaching the cable inside. Consider alternatives as follows:

    a. Leave the conduit empty and capped for future use if needed and bury the cable(s) directly in soil outside the conduit.

    b. Install a length of jacketed cable, with insulating jacket over the neutral wires, inside the conduit.

    c. (At pipeline crossings) Encase the cable in concrete with care to avoid damage later due to settlement. A split nonmetallic conduit may be useful as a form.

    d. Use a steel conduit with a stub of wire brazed at both ends and connect to the neutral, to provide cathodic protection of the neutral wires inside. (Note that with steel, magnetic effects may cause heating for single-phase or unbalanced multiphase loads.)

    e. Install a zinc ribbon anode with the core wire solidly connected to the nuetral wires, preferably at both ends of the conduit.

4. If costs of cathodic protection appear excessive, consider the use of cable with an insulating jacket over the neutral wires. Specify cables with neutral conductivity sufficient to carry maximum line-to-ground fault current. Install with sufficient grounding to assure adequate safety and electrical protection.

5. Avoid the use of conductive (semicon) jacketing over neutral wires of cable in contact with soil until improved formulations are available.[5]

Station Grounding

Substation grounds are generally large in extent and low in resistance-to-earth compared with the grounds of other nearby facilities. Therefore, it is important to recognize interactions between substation grounds and other buried metal within and near the station.

Steel-grounded stations. Galvanized steel grounding materials are desirable in distribution substations for the same reasons as in grounding of distribution lines. Galvanized, rather than ungalvanized, steel is suggested for additional protection against corrosion and for easier checking later (by measuring half cell potentials) to verify freedom from corrosion. Galvanized steel for ground rods and galvanized substation grounding conductor for substations are included in the List of Materials, REA Bulletin 43-5.

Steel has been used underground for grounding grids of generating stations and industrial installations of all sizes. Such installations require great amounts of sub-surface steel piping, tanks and piling so that there are major advantages in minimizing the extent of underground copper for grounding or other purposes. Overall corrosion protection then becomes easier to achieve either for coated or bare steel pipes and tanks underground.

Cathodic protection by use of sacrificial anodes becomes less expensive and easier to achieve to the extent that more steel materials and less copper is present in the ground grid. At the same time, the cathodic protection should be designed and maintained to assure integrity and durability of the grounding network. The following are suggested:

1. For substations with the grounding mostly with galvanized steel (for example, copper used only for interconnections between and surrounding equipment), include sacrificial anodes if earth resistivities are 2000 ohm-cm or less in the substation area.

2. For substations connected to direct-buried underground cables, apply additional cathodic protection (over and above the protection for the station ground) as necessary to control galvanic effects of the cable which might otherwise cause deterioration of the substation ground. Consider the use of jacketed cable (with an insulating jacket over the neutral wires) for sections near the substation to reduce cathodic protection requirements. (Note that jacketing is also suggested for cables in conduit.)

3. Include half cell potential measurements as a part of routine substation inspections. The dc potentials indicate the degree of continued effectiveness of galvanizing and anodes as well as indicating unforeseen changes which might indicate the need for additional corrosion control measures.

The goals for protection of a substation, in terms of half-cell potential of the grounding grid, may vary between -0.6 and -0.85 volt depending on prior experience and the degree of protection desired.

Copper-grounded substations. For a copper-grounded substation, use care to avoid steel or iron for underground conduit, hydraulic oil lines or any other structures in soil with a metallic connection to the station structure. (However, steel surrounded by concrete is usually protected against corrosion even when coupled with copper. Fence posts and gate posts for the station fence, properly installed in concrete, should have satisfactory resistance to underground corrosion.)

A copper-grounded low profile substation with underground exit feeders may be vulnerable to underground corrosion problems for the same reasons that apply to bare-neutral underground cable. Where such stations are present, they should receive first attention in underground corrosion checks or surveys.

1. Check important nearby underground steel structures including transmission anchors (if bonded to the static wire and station ground) for possible excessive corrosion.

2. Where little or no buried steel is present, observe half-cell potentials of the station ground as well as potentials of the cable neutral wires nearby. If half-cell potentials indicate probable copper corrosion, apply cathodic protection as necessary.

Copper substation grounds generally increase the probability of excessive corrosion of nearby distribution line anchors and also of transmission line anchors if the static wires are brought in directly to the station frame. However, the number of anchors near a substation may be so great that, with smaller stations in rural areas, the anchors are not seriously affected. Larger stations, more effective grounding and fewer nearby anchors may alter this situation.

A rectifier installation, rather than sacrificial anodes, may be needed to provide the capacity to achieve satisfactory cathodic protection of a large copper station ground and buried metal nearby. If so, three cautions are suggested:

1. The rectifier-type cathodic protection system should be installed and adjusted by someone with proven experience and competence. Improperly designed and/or adjusted, the rectifier may prove ineffective or cause damage.

2. On an existing station, make certain that neutral wires are not severed (or restore continuity if they are) before installing a rectifier, to avoid possible further damage to the neutral wires from operation of the rectifier.

3. Make certain that each rectifier is checked monthly as a part of normal operation to make certain that the rectifier is operating properly.

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2. Zastrow, O. W., "Copper Corrosion in Medium and High-Resistivity Soils," Materials Performance, Vol. 13, No. 8, pp. 30-37, August 1974. Summarized in "Concentric-Neutral Corrosion: Causes and Cures," Electrical World, Vol. 182, No. 4, pp. 46-79, August 15, 1974.

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5. Zastrow, O. W., Behavior in Soil of Underground Cable Neutral Wires and Jacketing Materials, Paper No. 154, presented at Corrosion/77, March 1977, NACE - The Corrosion Society, Houston, Texas.

MANUAL ON UNDERGROUND CORROSION IN RURAL ELECTRIC SYSTEMS

PART V. STRAY CURRENT CORROSION

PART V. STRAY CURRENT CORROSION

There are few corrosion-related topics in greater need of increased attention at the present moment than coordination between electric lines, above-ground and underground, and underground pipelines. Events not under our control have added urgency to the situation.

The Gas Pipeline Safety Act of 1968 imposes requirements for cathodic protection of practically all underground pipelines including bare and poorly coated pipelines. As we know, stray-current problems are very difficult to avoid when cathodic protection is applied to bare or poorly coated underground pipelines. Yet the law requires that such pipelines "must, not later than August 1, 1976, be cathodically protected... in areas in which active corrosion is found..." Active corrosion is broadly defined as "continuing corrosion which, unless controlled, could result in a condition that is detrimental to public safety."[1]

Meanwhile, underground pipelines and electric facilities, underground and above-ground, are being installed closer together and are often required to share the same right-of-way. It is our responsibility to discover ways of dealing with these situations, to minimize hazards to workers and the public.

Other dc sources are becoming more important and should be recognized as possible sources of stray-current interference. Chief among these are dc transit systems for surface transit and in mines, and high voltage dc (HVDC) power transmission.

CAUSES OF STRAY-CURRENT CORROSION

Stray-current corrosion, also referred to as electrolysis, occurs when direct currents from external sources find their way into electric system grounds, ground wires and neutral conductors. Corrosion occurs wherever the flow of direct current (movement of positive charge) is from metal into the soil.

Electrical grounding networks provide easy paths for any currents flowing in the earth. Thus, the necessary requirements for grounding make the electric system vulnerable to stray-current corrosion.

Stray-current corrosion may be much more rapid than other soil corrosion but it is also more localized, occurring only in the vicinity of dc sources. Probable sources are pipeline-protection rectifiers and the protected pipelines, dc electric facilities including high voltage dc (HVDC) transmission lines, and dc traction systems including dc-powered electrified railways and apparatus in mines.

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[1]Par. 192.457, Subpart I, Part 192, Title 49 of the Code of Federal Regulations, Department of Transportation, Office of Pipeline Safety, 400 7th St. S.W., Washington, D.C. 20590

Pipeline Protection Rectifiers

An impressed-current cathodic protection system with a rectifier as the dc source is shown in Fig. 1. The positive dc terminal of the rectifier is connected to an anode bed, usually of graphite or other special materials to resist destruction from the anodic reactions. The negative terminal is connected to the pipeline so that the pipeline becomes cathodic and is protected against corrosion. The anodes are usually placed at some distance from the pipeline. With the rectifier properly adjusted, the direct current flows toward the pipe at every location where its surface contacts the earth, over a considerable distance in the vicinity of the rectifier.

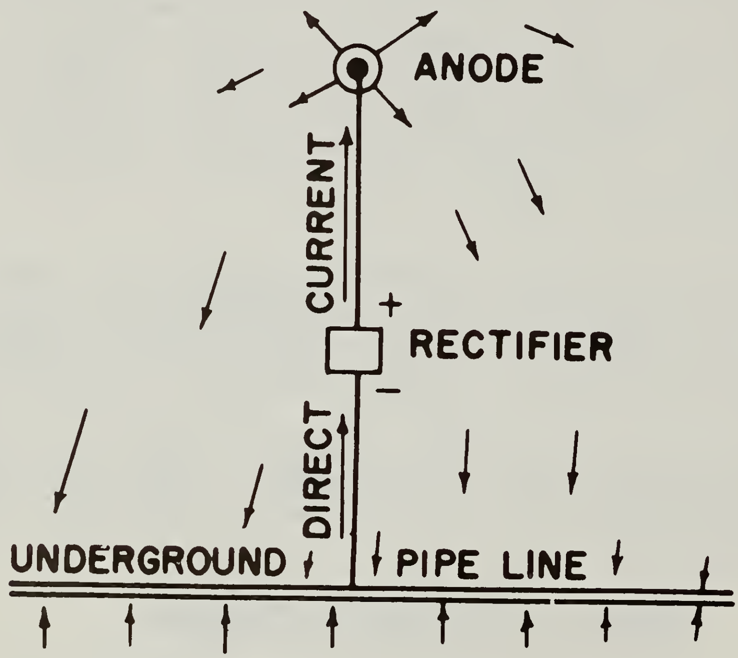

Fig. 1. Cathodic protection system using a rectifier as a dc source.

If the rectifier is served from an electric line as shown in Fig. 2, the electric grounds and the neutral conductor provide alternative paths for the direct currents between rectifier anodes and the protected pipeline. In this illustration, the anodes are installed along the pole line right-of-way. The direct current from the anodes goes to nearby pole protection grounds and onto the neutral conductor. The grounds near the anode bed become cathodes and are protected against corrosion. However, at other remote locations, the current returns to earth, causing corrosion at grounds and other buried metal structures connected to the neutral, which become anodes. In Fig. 2, part of the current is returning to earth near the protected pipeline so that corrosion is occurring to ground electrodes near the pipeline. Most of the current is flowing along the neutral in both directions, away from the rectifier. Corrosion can be expected at all locations where these currents return to earth.

Direct-buried cable with bare neutral wires is vulnerable to corrosion in the same way as a bare "foreign" pipeline, if the cable passes near the anode

bed or near the protected pipeline (Fig. 3). The copper neutral wires are small, usually No. 14 AWG (1.63 mm) or No. 12 AWG (2.05 mm), so that even a small amount of corrosion may sever the wires. Neutral wires are also vulnerable to corrosion where the cable crosses a cathodically protected pipeline.

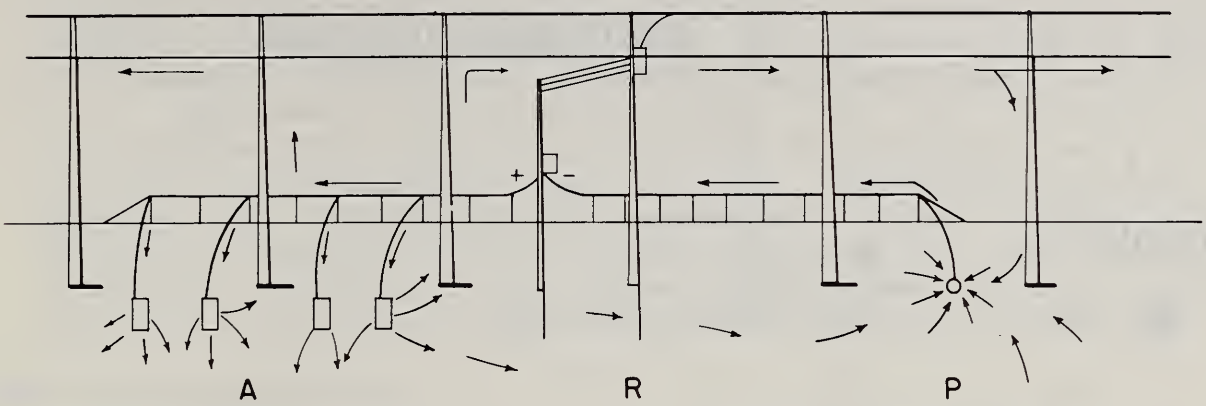

Fig. 2. Diagram of a pipeline protection rectifier causing damage to grounds of a distribution line (A) anodes; (R) rectifier; (P) protected pipeline.

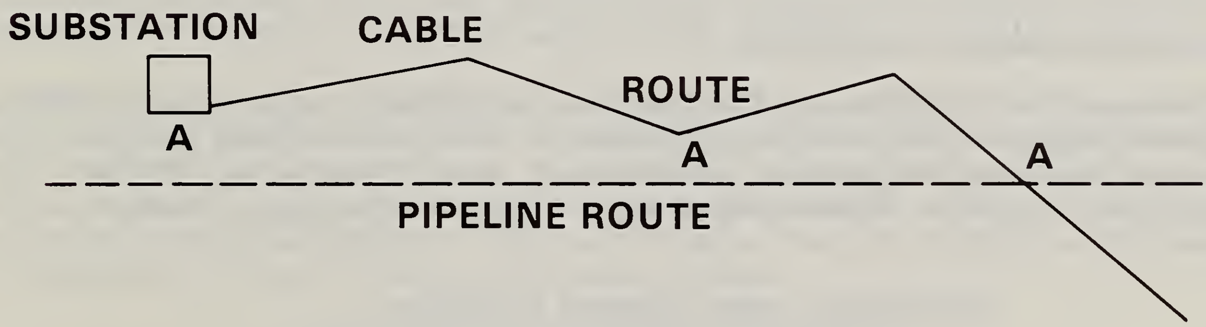

Fig. 3 Underground cable route and electric distribution substation near a pipeline. Anodic areas and cable neutral corrosion are likely at locations A.

The ground grid of a distribution substation located as shown in Fig. 3, could be dangerously vulnerable to stray-current corrosion. Such a station should be located elsewhere if possible. Otherwise, corrective measures are needed to assure permanence of the station ground.

High Voltage Dc Transmission Lines

Conditions favorable to stray-current corrosion may occur along HVDC lines during periods of ground-return or unbalanced operation. The most probable locations of difficulty are in the vicinity of the ground electrode at each terminal. The actual locations of corrosion will differ with direction of the current at the grounding electrode. When the electrode is cathodic,

currents in the earth are toward the electrode and corrosion would be probable at locations nearest the electrode (Fig. 4). If the electrode is anodic, the currents would be reversed, the nearby locations would be protected and corrosion would occur at the more remote locations marked C in Fig. 4.

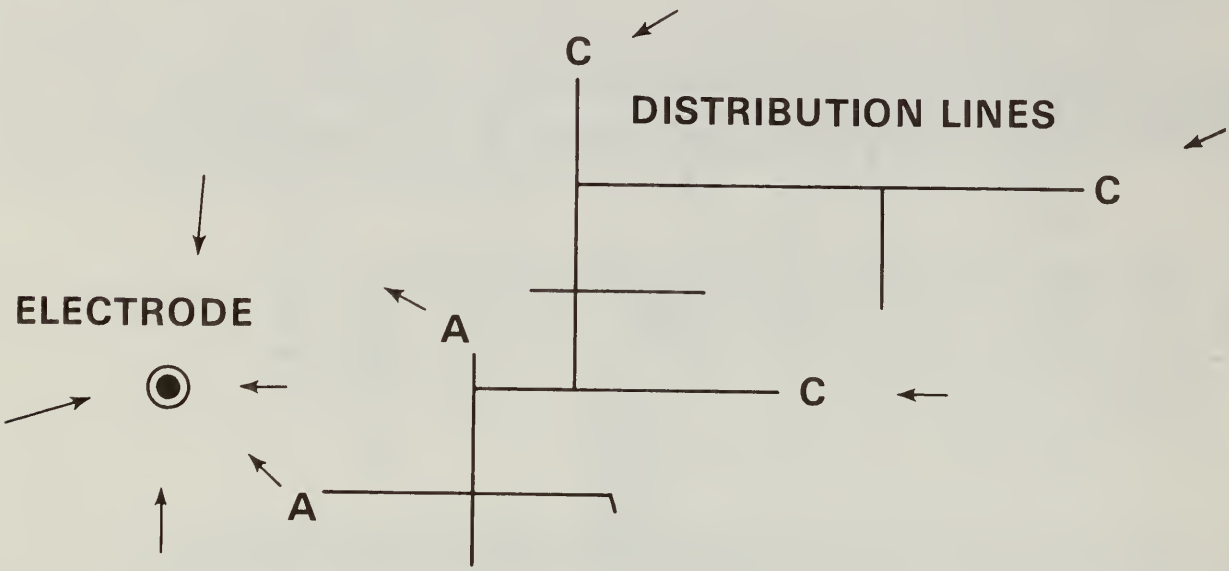

Fig. 4. Stray currents affecting electric distribution line neutrals, anchors and grounds near grounding electrode of an HVDC transmission line, during unbalanced operation of HVDC electrode acting as a cathode.

Dc Electrified Railways and Mines

The existence of dc traction systems may seem unlikely in most areas. However, such systems do exist and more may be built in the future. They may give erratic and confusing indications on corrosion test instruments. The dc potentials and currents change with starts, stops and passage of cars or trains.

RECOGNIZING STRAY CURRENT CORROSION

Stray-current effects can be detected by means of electrical measurements before there is other evidence of corrosion. This is the choice we would prefer. However, the difficulties may not have been foreseen and if so, the first evidence of trouble is corrosion of grounds, anchor assemblies or other buried grounded metallic structures. The first above-ground evidence may be a slack guy, abnormal neutral voltages or shocks due to loss of grounding, or leaky water pipes.

Warning Signals

The following are symptoms to watch for in areas of probable stray-current corrosion, particularly near pipeline protection rectifiers, along pipelines and at pipeline crossings:

1. Slack guys, if guys are bonded to the electric neutral.

2. Abnormal corrosion of anchors, grounds and ground wires, found during line changes or visible at the ground line.

3. Unusual accumulations of lime or other deposits on ground rods, anchor rods and ground wires (in cathodic locations of current "pick up") near a rectifier anode bed.

4. Indications of abnormal ac voltages on neutrals, grounds and grounded enclosures. These may take the form of complaints of electrical shock, refusal of cattle to drink from watering cups or a stock tank, or sparking between metal doors or enclosures when contacting a grounded metallic pipe or post. (Note, however, that these can occur in absence of corrosion, from difficult grounding or abnormal power line conditions.)

5. In corrosion surveys, half-cell potentials more negative than -0.8 to -0.9 volt, or more positive than +0.3 volt. Potentials in the more positive range indicate probable locations of current "drainage" and corrosion, which are likely at pipeline crossings and parallels with pipelines. Potentials in the extreme negative range indicate probable locations of current "pick up" such as near a rectifier anode bed.

Field Testing and Surveys

A few brief measurements of half cell potentials will usually confirm whether or not stray current corrosion is occurring. As experience is gained, abnormal dc potentials should be easily recognized. If a suitable test meter is available, currents in guys (assuming they are connected to the neutral) may also be a useful indication of corrosion or freedom from corrosion of nearby grounds as well as the anchor assemblies. Guy currents, potential measurements or both may be helpful for monitoring parallels or crossings of electric lines and underground pipelines.

Assistance should be requested from the pipeline owner if objectionable stray-current effects are found or suspected. The pipeline people recognize that they have a responsibility for avoiding damaging effects of the protection systems; they have knowledge and experience in stray-current testing, and they need to be informed about any changes that might make a difference in operation of the cathodic protection system.

CORRECTIVE AND PREVENTIVE MEASURES

Stray-current corrosion in electrical grounding networks can be minimized or avoided by steps such as the following:

1. Install galvanic anodes.

2. Connect the protected structure (pipeline) to the electric neutral or ground, by means of a direct connection or through a resistance.

3. Use coatings and/or insulation.

4. Relocate a structure, an anode bed or an entire facility (the electric line or pipeline) to provide more separation.

5. In new construction, take maximum advantage of separation, insulation and coordinated protection.

The key to good results is cooperation. A clear understanding is needed of both the pipeline protection system and the electrical grounding.

Underground Cable and Pipeline Crossings

In Fig. 5, dc toward the pipe is following a path of least resistance along the bare concentric neutral wires. (Arrows are in the direction of movement of positive charge.) For the neutral wire, the anodic surfaces and corrosion are at the location where the current is drawn off, nearest the pipe. The corrosion will progress backward away from the crossing as the nearest neutral wires disappear.

A protective sleeve over the cable reduces the intensity of the stray current, at least at the beginning, and moves the location of damage back to the end of the sleeve. However, it has not really solved the problem as may be seen in Fig. 6. In addition, cable neutrals may be vulnerable to corrosion inside the protective sleeve.

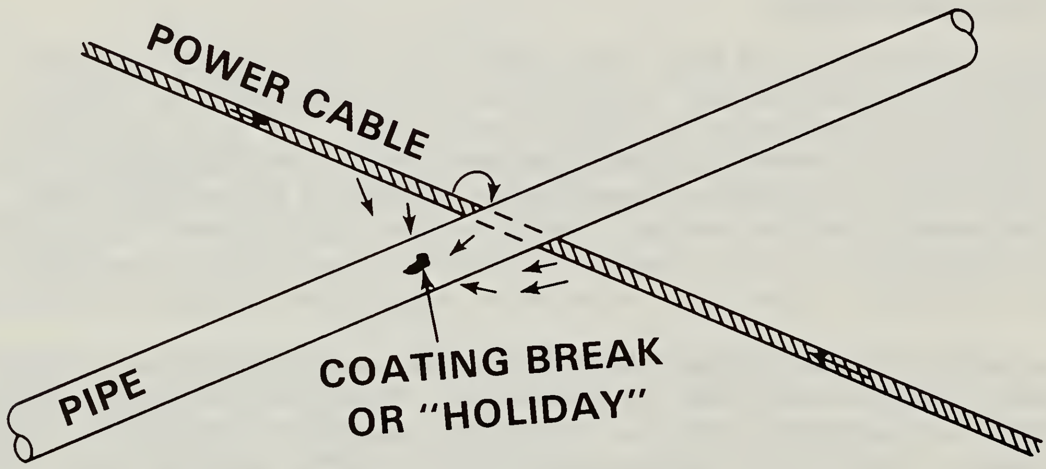

Fig. 5. Stray-current corrosion of cable neutral wires at a pipeline crossing.

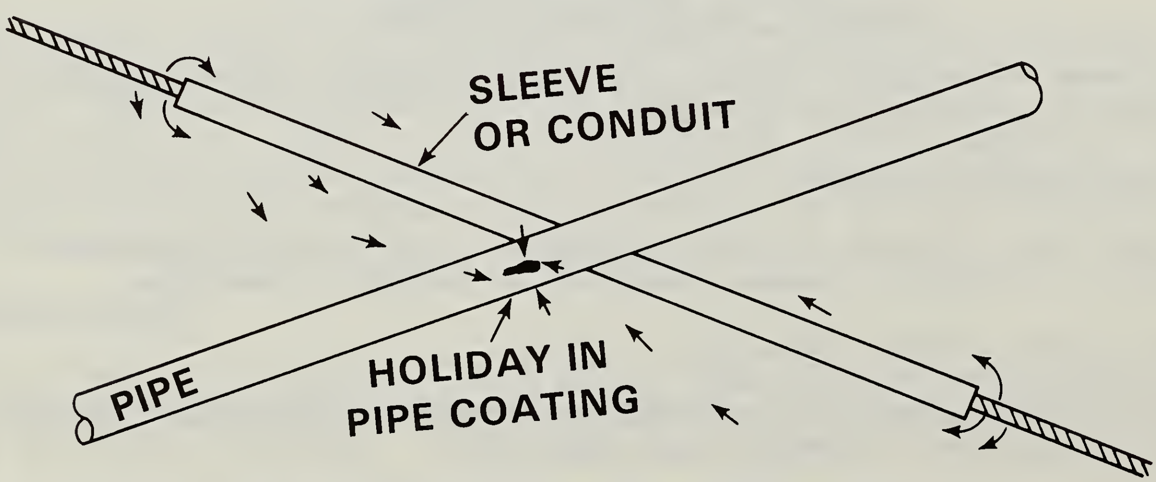

Fig. 6. Underground cable and pipeline crossing with a protective sleeve over the cable.

An interference bond, shown in Fig. 7 is an effective way to protect cable neutrals against stray-current corrosion. The stray dc on the cable neutral wires is being returned to the pipe by means of a metallic connection. The amount is controlled by means of a resistor or resistance wire in the test box. (A separate wire from cable to test box provides a means for checking dc potential of the cable while the current flows in the other wire.)

As an alternative to the interference bond, one or more sacrificial anodes might be installed as shown in Fig. 8. The stray current is "drained" near the pipeline via the anodes instead of the neutral wires. With properly sized anodes and a good pipeline coating, the anodes may remain effective for many years.

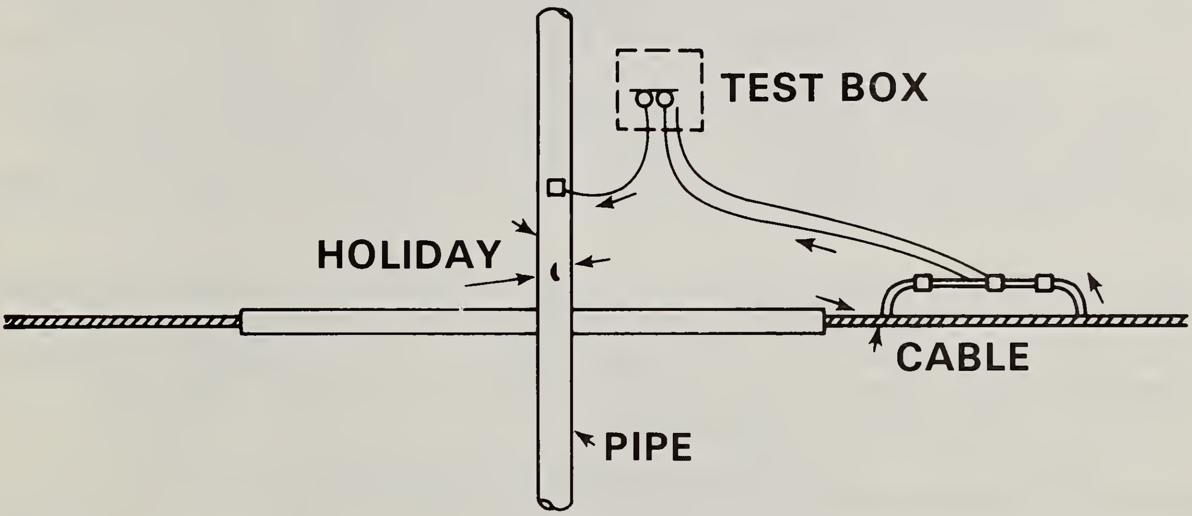

Fig. 7. Underground cable and pipeline crossing with interference bond to protect cable.*

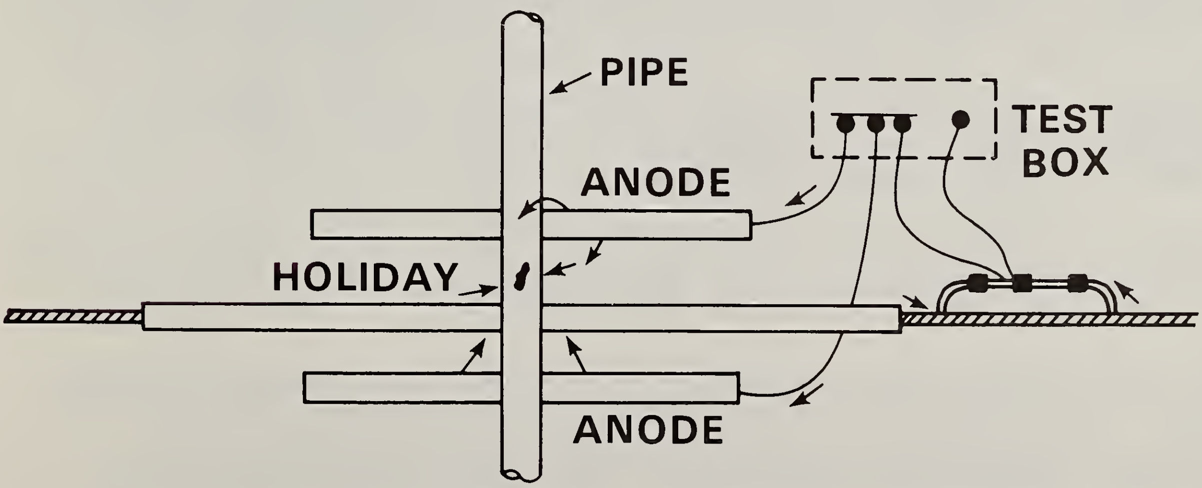

Fig. 8. Underground cable and pipeline crossing with anodes installed for protection of cable.*

*For cautions regarding cables in conduit, see Part IV, page 19.

One obvious helpful step is to repair the break in the pipeline coating, to eliminate most of the dc toward the pipeline at that location.

In summary, steps for control of corrosion at a cable-pipeline crossing are as follows:

1. During installation, use care to avoid damaging the pipeline coating. Repair any damage to the coating in the vicinity of the crossing.

2. For a bare or poorly coated pipe, make repairs or apply a new coating near the crossing.

3. Provide protection to the cable by means of an insulating jacket, encasement in concrete, conduit, or a combination of these. If conduit is used, use cable with jacketing over the neutral wires inside the conduit.

4. Install a resistance bond or anodes to assure that neutral wires are protected against corrosion. (For a well coated pipe, an anode or anodes may be sufficient. For a bare or poorly coated pipe, a resistance bond is likely to be necessary.)

5. Make periodic checks at 6-month or 1-year intervals as a part of normal maintenance, to make certain that protection of the neutral wires continues to be effective. This may be done by checking the dc neutral potential from a close copper-copper sulfate half cell, using the connection available at the test box.

<u>Pole Line and Pipeline Crossing with Service to a Rectifier</u>

At locations near a rectifier, effects of the anode bed may be more serious than proximity of grounds to the pipeline. The situation illustrated in Fig. 2 includes both. In the figure, dc is being drawn from pole protection grounds near the pipeline. These grounds are corroded as a result. After nearby grounds are destroyed, the damage may cease. However, grounds near the anode bed behave much differently. They are cathodes and are protected against corrosion. The corrosion occurs at other locations, where the dc returns to earth. The nearest, lowest-resistance ground connections are corroded first. As they are destroyed, the remote and high resistance grounds come into play. This will be corrected only when someone recognizes the situation and does something about it.

Stray-current corrosion can be avoided at the rectifier and pipeline crossing by providing more separation and by a bond between the pipeline and electric neutral. The steps, shown in Fig. 9, are as follows:

1. Near the pipeline, remove grounds (such as the pole protection grounds near the pipeline) which are not required for equipment grounding and/or safety. If an anchor is located near the pipeline, install a guy insulator. (This is one place where a guy insulator <u>is</u> desirable.)

2. Near the anodes, remove nonessential grounds such as the pole protection grounds that were near the anodes in Fig. 2.

3. Install a resistance bond at the rectifier, to provide a return path for stray currents that might still cause difficulty.

4. If a required ground (such as at the transformer) is too near to the pipeline or anode bed for satisfactory corrosion control, move the equipment and its ground to another location. If necessary, use a longer secondary service to the rectifier.

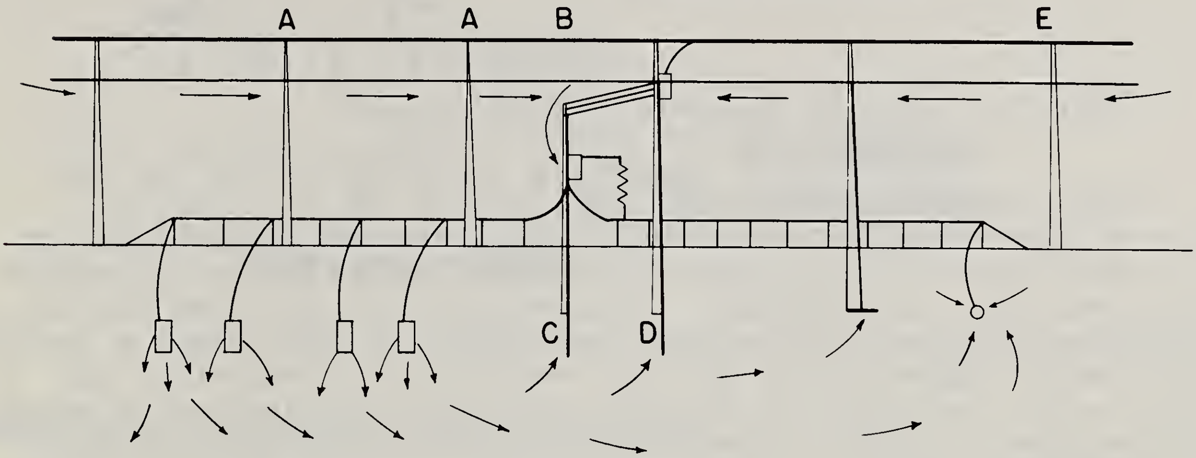

Fig. 9. Pipeline crossing and service to rectifier with electric grounds protected.

Pipeline Parallel with Electric Distribution Lines

Stray-current problems may arise if a pipeline is near an electric line, even when they do not cross each other. The corrective steps called for will differ according to physical arrangement of the pipes and electric grounds and/or cables, the condition of pipeline coatings, underground congestion including facilities owned by others and possible obstacles to agreement about what should be done.

As a first example, Fig. 10 shows the underground cable route and substation as in Fig 3, with a resistance bond installed at the crossing. How shall we avoid stray-current corrosion of bare cable neutral wires at A and the substation ground at B? The following measures are available:

- o Insist on a good coating (installed by the pipeline company) on the pipeline.
- o Connect anodes to the neutral for drainage at A and/or B.
- o Request a resistance bond between the pipeline and neutral at A and/or B, and install in cooperation with the pipeline company.

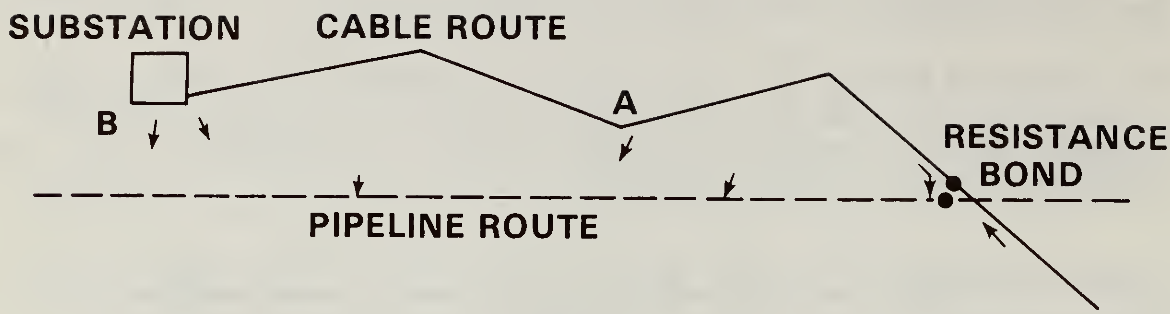

Fig. 10. Cable and pipeline in parallel with resistance bond at nearby crossing.

Fig. 11 shows how sacrificial anodes might protect the cable neutral wires at A. The anodes and connecting leads provide the easiest path for dc. Now the current discharge and the corrosion are at the anodes and the cable neutral wires are protected. The anodes work to best advantage if the stray currents are small (as when the pipeline is well coated or quite distant from the cable) and if the earth resistivity is moderately low. For high-resistivity soils (20,000 ohm-cm or higher) and for bare or poorly coated pipelines, a resistance bond between cable and pipeline is likely to be necessary.

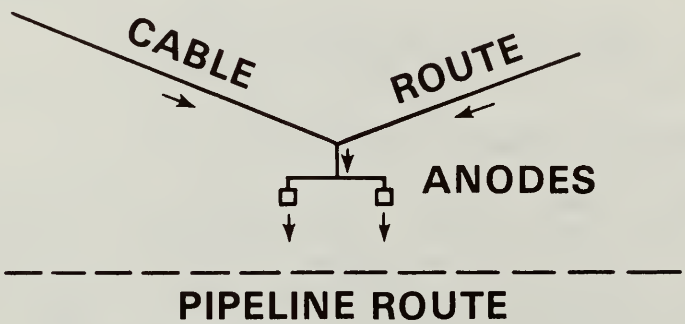

Fig. 11. Stray current protection of cable neutrals by use of sacrificial anodes.

At the substation (B in Fig. 10), the grounds are crucial for safety and system electrical protection. They also are difficult to protect against corrosion because of the low resistance-to-earth of the substation ground. Anodes for stray current drainage might be located as shown in Fig. 12 along the perimeter of the substation. An alternate location nearer to the pipeline may be more effective if the connecting cable is safe from accidental damage.

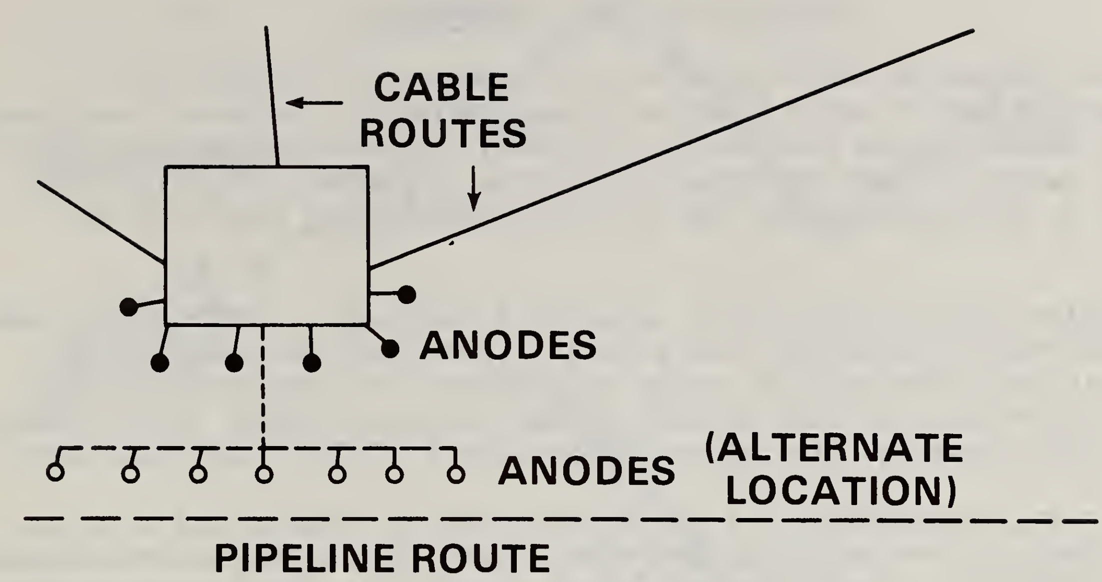

Fig. 12. Stray current protection with sacrifical anodes at a substation.

Pipeline Near an Electric Transmission Line

From the standpoint of stray currents and pipeline coordination, an electric transmission line with a static wire has some similarities to a multigrounded distribution line but there are also some important differences. The transmission line has higher voltages, it has more energy available under fault conditions and it is generally not as solidly grounded as a distribution line. Consequently, some important differences in coordination practices are necessary:

1. The difficulties due to possible electrical surges and induced ac on the pipeline may be a major consideration in coordinating with high-capacity transmission lines such as those at voltages above 69 kV. The possibility of these difficulties should be recognized when deciding on measures for dc (stray-current) coordination.

2. Bonds between a pipeline and transmission structure or ground should be avoided to the maximum extent possible, to minimize the possible transfer of surges to the pipeline and along it. The preferred strategy is maximum separation or isolation in combination with grounding of the pipeline with anodes. This is particularly true for delta-connected transmission lines without automatic ground fault protection.

3. If a bond is needed, the resistance wire may need frequent replacement because of surges unless it can be designed for high energy absorption and includes a discharge gap to bypass surges. A solid bond, on the other hand, may result in an undesirable transfer of electrical surges to the pipeline.

TESTING FOR STRAY CURRENTS

Stray-current testing, and mitigation of stray-current effects is a specialized subject on which pipeline companies have accumulated considerable amounts of knowledge and experience. If stray-current problems are found or suspected, owners of the underground pipelines should be called upon for assistance in performing tests and in corrective actions when such are needed.

A few examples will be given of dc potentials that may be observed in cases of stray-current interference from pipeline protection rectifiers. For more detailed information, the reader should refer to literature on this subject in technical journals including publications of NACE, The Corrosion Society (until recently, the National Association of Corrosion Engineers).

In interpreting dc potential measurements, pipeline company people should recognize that a bare-neutral underground cable has the same characteristics as a bare pipeline. A multigrounded electric pole line behaves similarly to a coated pipeline with a holiday at every ground connection.

Potentials. Half cell potential measurements (to a copper-copper sulfate half cell) provide a quick measurement to identify "current pick up" (cathodic) areas as well as corroding (anodic) areas where dc is returning to earth from the electric neutral. Table I and Fig. 13 show examples of dc neutral potentials that might result during severe stray-current interference from a bare pipeline and rectifier for cathodic protection.

TABLE I

Sample Half-Cell Potentials of Electric Neutrals Near a Cathodic Protection Rectifier and Pipeline

Locations	Potentials (volts)
Near bare protected pipeline	+1.2
Near rectifier anode bed	-2.0
½ mile from rectifier or pipeline	+1.5,* or -1.0**

*If grounds near rectifier are too close to the anode bed.
**If grounds near the pipeline are draining current.

Potential gradients. Stray dc currents in the earth cause a voltage drop which can be measured by means of a dc voltmeter and either one or two copper-copper sulfate half cells. Fig. 14 shows how a potential meter can be used with two half cells to identify stray currents and probable corrosion of an underground cable neutral. Or, the dc neutral potential can be observed with a half cell placed at a number of locations in a circular pattern as shown in Fig. 15.

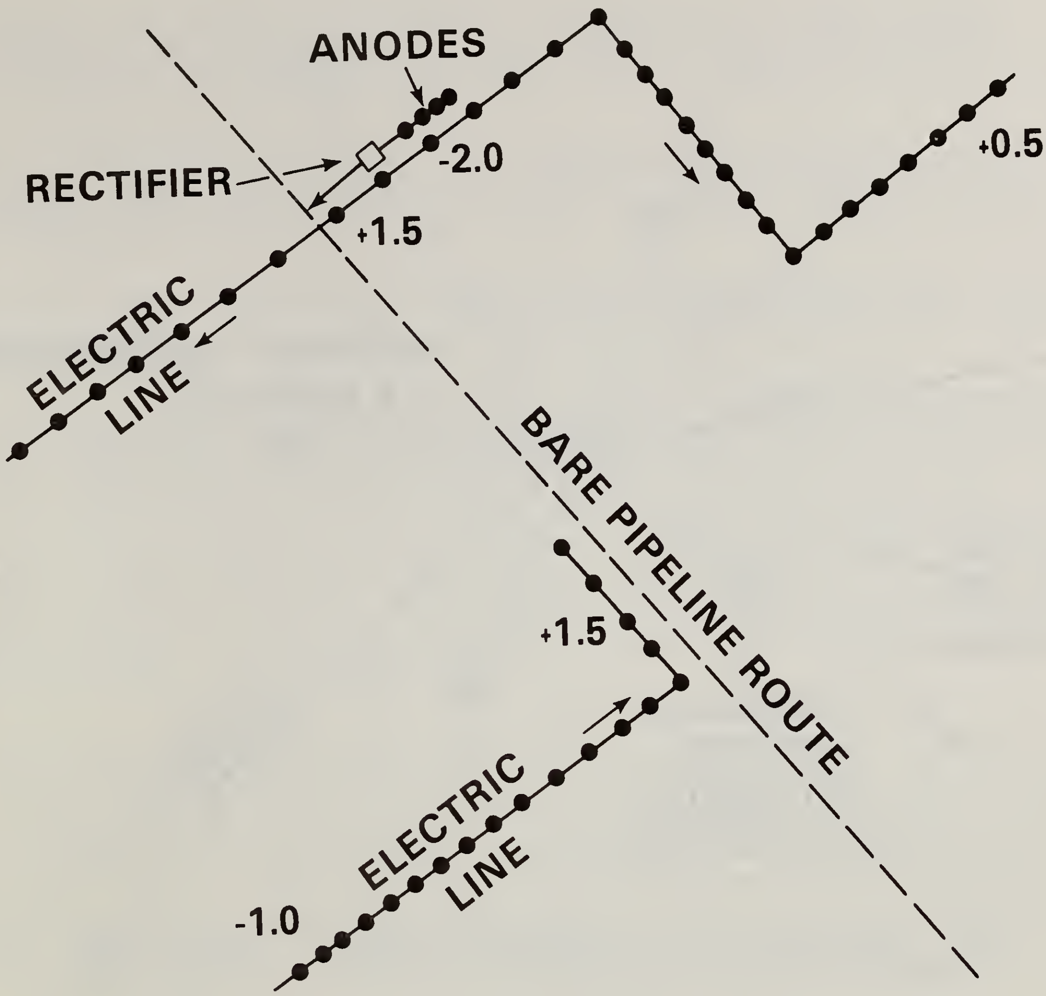

Fig. 13. Sample dc neutral potentials near a bare pipeline and cathodic protection rectifier. All measurements are to a copper-copper sulfate half cell.

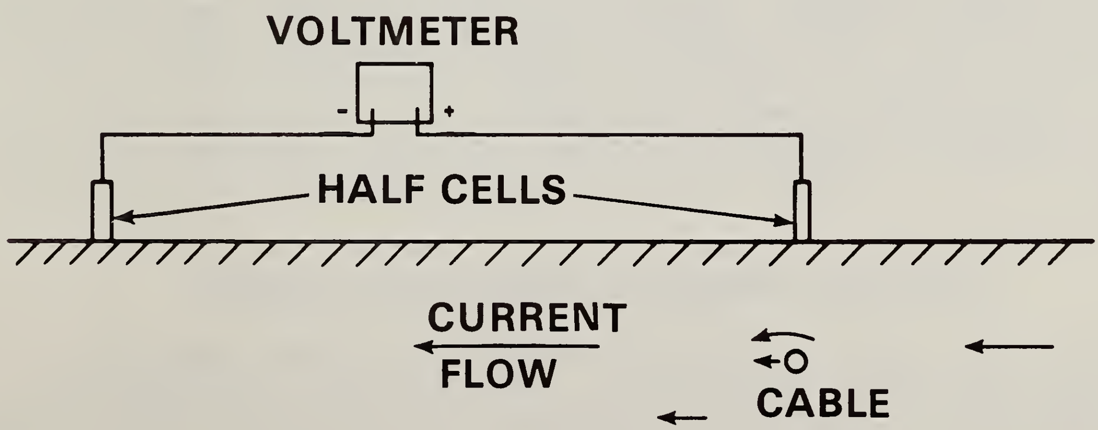

Fig. 14. Measurement of potential gradient due to stray current across an underground cable, with potential meter and two copper-copper sulfate half cells.

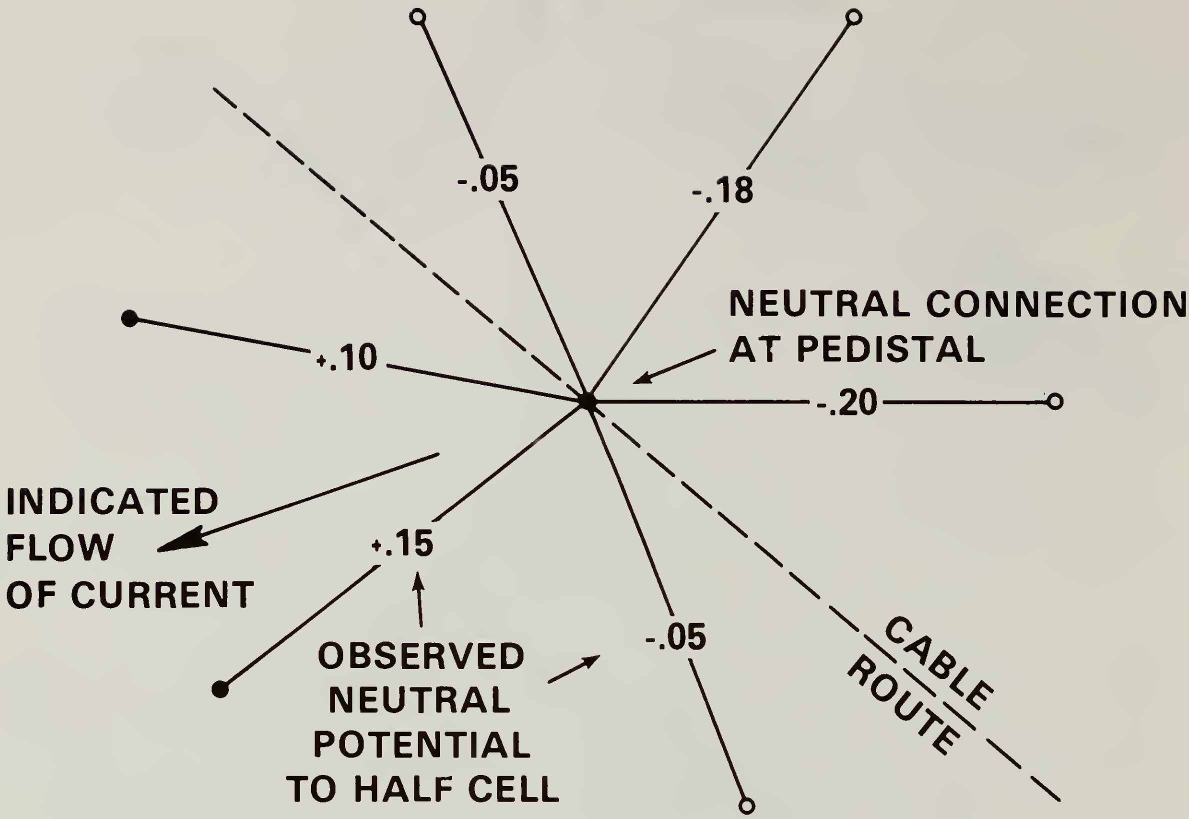

Fig. 15. Effect of dc potential gradient (due to stray currents) on neutral-to-half-cell potential measurements.

Guy currents. Guy current measurements (in guys connected to the neutral) may be useful in helping identify stray currents and also for determining later whether corrective measures are effective.

Identifying Dc Sources

Preliminary tests such as those already described may point to obvious sources of stray currents. However, in some situations the observations may be confusing. This is likely to occur in congested areas or where there are unknown contacts or connections between the neutral and other facilities that are underground or partly underground. In either event, the owner(s) of the underground pipeline(s) or other facilities should be called upon for joint tests to further define the problem and decide on corrective actions.

COOPERATIVE HANDLING OF STRAY-CURRENT PROBLEMS

To a high degree, good results in corrosion coordination depend on cooperation and mutual understanding. This can not be overemphasized. Some suggestions for success are available from experience over many years in coordination of electric and communication circuits, to prevent communication interference. The suggested rules to follow are:

1. Approach the problem with the aim of finding the least costly acceptable solution, based on total cost, as though one owner were responsible for both facilities.

2. Avoid discussing responsibility, either for the trouble or for remedies, but concentrate on analysis of the problem and choices available for correcting it.

3. Once the "best engineering solution" has been decided upon, decide how the work should be done and costs should be shared.

An illustration may help to illustrate how this would work in practice. At a corrosion short course last year, a pipeliner asked what might be done about possible interference while polarizing a bare pipeline that paralleled and electric line a quarter mile away. The answer was, to sit down with an engineer with the electric company or cooperative, with maps of both facilities, then decide on locations for test points and drain points if needed. The electric organization might also have equipment as well as the competence for installing a few anodes and connecting cables at a minimum cost.

Effective coordination requires a suitable organizational framework as well as good intentions. Here, again, there is experience to draw upon. Special underground corrosion coordinating committees have been created in many areas of the United States. The nearest coordinating committee in your area can be located by directing an inquiry to the nearest major pipeline company or to the National Association of Corrosion Engineers, P. O. Box 1499, Houston, Texas 77001/Phone: (713) 532-8980.

REFERENCE

Par. 192.456, Subpart I, Part 192, Title 49 of the Code of Federal Regulations, Department of Transportation, Office of Pipeline Safety, 400 7th St. S.W., Washington, D.C. 20590

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